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Twenty-Second Award of the William Bowie Medal

Biographical Sketch of Francis Birch

Prepared by MAURICE EWING

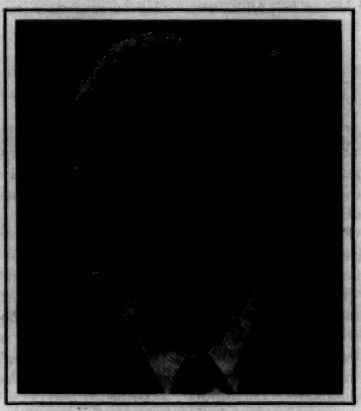
Francis Birch has been a distinguished contributor to geophysical research for more than 30 years. He has treated many fundamental problems of the interior of the Earth in a rigorous and decisive manner.

Birch has particular competence in engineering, in physical science, and in geology. He has brought the full power of these disciplines to bear in his studies of the properties of rocks under the extreme conditions which prevail within the mantle of the Earth.

He received three degrees from Harvard: Bachelor of Science in Engineering (1924), Master of Arts (1929), and Doctor of Philosophy in Physics (1932). As student and as teacher, he has spent forty years at Harvard, with brief intermissions at the New York Telephone Company (1924–26), the University of Strasbourg (1926–28), and for war work at the Bureau of Ships, the Radiation Laboratory, and Los Alamos (1942–45).

He has served Harvard well, by ensuring continuation of major parts of the work of both Daly and Bridgman. Since 1949 he has held one of the most distinguished posts in geological science—the Sturgis Hooper Professorship—as the worthy successor of Davis and Daly.

Birch has made many significant contributions to the interpretation of seismic data. Much of his work has consisted of laboratory studies of the velocities of elastic waves in rocks and their variation with pressure and tempera-



Francis Birch

ture. Out of this work came the first physical evidence that the old concept of a 'vitreous basaltic substratum' was untenable. In a major theoretical work, Birch pioneered in the application of the methods of chemical physics to the constitution of the Earth's interior.

He has also contributed heavily to our knowledge of terrestrial heat flow. His work on the Front Range is a classic in this field, and he has carried out important studies in other parts of this country. It was largely through his efforts that the thermal conductivity of rocks, and its dependence on temperature and composition, became known. In recent years he has supplemented these lines of endeavor with studies of mineral stability at high temperatures and pressures.

His accomplishments have been widely recognized, as evidenced by his election to the American Academy of Arts and Sciences (1942), the National Academy of Sciences (1950), and the American Philosophical Society (1955). His decorations include the Legion of Merit (1945) and the Day Medal of the Geological Society of America (1950).

The record of his work is to be found, of course, in his scientific papers, of which there are about fifty. But one publication, *Special Paper No. 36*, the *Handbook of Physical Constants*, edited and compiled under the guidance of Birch, has probably been as helpful as any geophysical publication to those who are trying to put Earth science on a quantitative basis.

Beno Gutenberg was Chairman of the Committee which nominated Francis Birch for the Bowie Medal. His high esteem of Birch's work had been reconfirmed during the comprehensive literature review made in preparation of *Physics of the Earth's Interior*, that enduring legacy which Beno Gutenberg left to us all. Knowing that he could not be here to present this citation, he sent some informal remarks on the work of our medalist in a letter dated January 18, 1960. I consider these a most appropriate appraisal, certain to be cherished by Francis Birch.

"Among the points which I am considering important in Birch's research are his attempts to study the properties of the materials which we suppose to form the Earth. Moreover, his research on the temperature gradients in the Earth's crust, I consider of great importance. Apparently he and Clark were the first to point out the possible importance of radiative heat in the Earth's mantle (1940). The paper of Birch which I, personally, consider at least one of the most important is the one on *Elasticity and Constitution of the Earth's Interior, Journal of Geophysical Research*, 57, 227–286, 1952. This includes his suggestion that phase changes may play an important role in the Earth's mantle."

Citation

PREPARED AND PRESENTED BY PERRY BYERLY

I am taking the place of Maurice Ewing who is on another expedition at sea. I have one important qualification for making this citation; I have paid Francis Birch the highest compliment one Professor can pay another. I sent my son to him for graduate work. Francis responded by giving him a Doctor's degree.

Birch was trained as an engineer and physicist but had an interest in geology. He mastered Bridgman's techniques and decided to apply them to Daly's problems set forth so ably in Daly's *Strength and Structure of the Earth*. Francis succeeded Daly in the most dignified chair of geology in the United States, the Sturgis Hooper Professorship. The presentation of the Bowie Medal tonight honors the Geology Department at Harvard as well as Francis Birch. There were indeed wise heads at Harvard who saw the trend of advancing geology and were willing to give their honored chair to a physicist-engineer.

Birch's work on heat flow in the Front Range is a classic. He made use of the drilling of the Moffat tunnel to gain invaluable data.

Many a geophysicist has blessed his name for compiling the *Handbook of Physical Constants* to which we all refer often. You will note in the Biography Gutenberg's praise for his treatise on *Elasticity and Constitution of the Earth's Interior*.

Birch has suggested that some seismological discontinuities in the Earth may represent

changes in state rather than chemical changes. This idea has been so intriguing that the *Mohole Project* has taken hold. Although I understand Francis is not too much sold on it, and, although he will not be the midwife who brings it into being, I am afraid whether he likes it or not he is the daddy of the Mohole.

Mr. President, I give you Francis Birch, a man who has done most to modernize geology, a man thoroughly worthy of the Bowie Medal.

Presentation

LLOYD V. BERKNER

Francis Birch, on behalf of the members of the American Geophysical Union and by the authority of the Executive Committee, I am honored to present to you the Twenty-Second Award of the William Bowie Medal for "unselfish cooperation in research."

Acceptance and Response

FRANCIS BIRCH

President Berkner and members of the American Geophysical Union: I am very grateful to Professor Ewing and Professor Byerly for their generous citations, and especially for the transmission of Professor Gutenberg's remarks.

An honor such as the William Bowie Medal leaves the recipient in a state of pleasant shock; he can only marvel at the inscrutable operation of committees, somehow able to make an annual selection from the many dozens of eligible candidates in geophysics. Perhaps the 'cooperative' element in this award suggests a clue, with the implication that the chosen individual really represents an institution or group whose collaborative efforts are given this gratifying approval, the only kind of approval which counts for most of us, that of others engaged in the same pursuits.

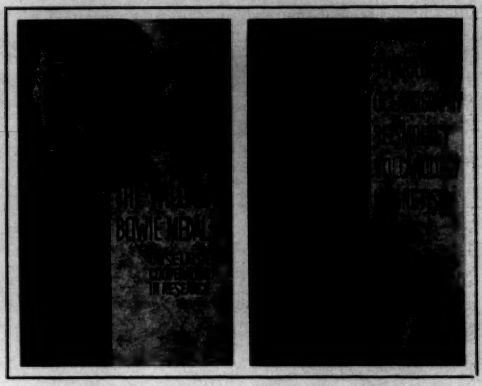
There is an explanation of how a university becomes a place of learning, credited to Mr. Lowell: "Each freshman brings a little learning, the seniors do not take it away, and so it accumulates."

It seems to me that a process resembling this works to the advantage of those of us who have to do with a succession of graduate students and post-doctoral fellows. Each of them educates us a little, and their contributions come to be identified with our own, greatly magnifying the total. I hope that they do take something away, and in particular, that those who have worked with me over the last thirty years will feel part ownership in this Medal and the highly valued recognition which it signifies.

Previous Recipients of the William Bowie Medal

The previous recipients of the William Bowie Medal, with the dates of their awards, are as follows:

William Bowie (deceased).....1939
Arthur Louis Day (deceased).....1940
John Adam Fleming (deceased).....1941
Nicholas Hunter Heck (deceased).....1942
Oscar Edward Meinzer (deceased).....1943
Henry Bryant Bigelow.....1944
Jakob Aall Bonnevie Bjerknes.....1945
Reginald Alsworth Daly (deceased).....1946
Felix Andries Vening Meinesz.....1947
James Bernard Macelwane (deceased).....1948
Walter Davis Lambert.....1949
Leason Heberling Adams.....1950
Harald Ulrik Sverdrup (deceased).....1951
Harold Jeffreys.....1952
Beno Gutenberg (deceased).....1953
Richard Montgomery Field.....1954
Walter Hermann Bucher.....1955
Weikko Aleksanteri Heiskanen.....1956
William Maurice Ewing.....1957
Johannes Theodoor Thijsse.....1958
Walter Maurice Elsasser.....1959



The William Bowie Medal (actual size 2" x 3¼")

United States National Report, 1957-1960

Twelfth General Assembly

International Union of Geodesy and Geophysics

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United States National Report, 1957-1960

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President's Page

THE TRIENNIAL REPORT TO THE IUGG[1]

Prepared by the Editor, Leason H. Adams, upon the invitation of the President, Lloyd V. Berkner

When we reflect on the origin and history of geophysics, it is thought-provoking to single out three epochs of especial significance, separated from each other by about one millenium. The record shows that over two thousand years have passed since the beginning of serious geophysical thought. Indeed it was a few centuries before the start of the Christian era that Pythagoras came to the conclusion that the Earth has a spherical form; and about this time the early philosophers were able to make an estimate of the circumference of our globe, not merely to a crude approximation, but with truly remarkable accuracy in consideration of the state of science and the measuring tools available in those days. This was a noteworthy achievement in that it profoundly altered man's thinking in relation to the Earth and even the Universe. As we follow swiftly the development of science throughout the succeeding centuries, we may pause to note that something like ten centuries after our first epoch, a second notable advance in culture, in this instance within the Arabic countries, led to an extraordinary broadening of knowledge in many realms of science, including those bearing on an understanding of our Earth and its surroundings. This, strangely enough, happened during the very period in world history that over-laps what for Europe has been called the Dark Ages.

And now, after another ten centuries, has occurred what we may call a third major epoch in geophysical progress, this time of vastly wider and deeper significance than ever before. In the last few decades, attention has turned with increasing rapidity from the thin superficial layer accessible to geologic exploration to the deeper parts of the Earth—to the upper atmosphere—and to the strange magnetic and electrical effects associated with our globe and its gaseous envelope. This accelerated advance has paralleled the remarkable progress we have seen in many other fields of scientific endeavor. Indeed, our most revolutionary recent discoveries in Earth science were inspired by, or based on, new knowledge in physics, chemistry, and mathematics; and without the aid of powerful tools developed in the realm of physical sciences, geophysics could not conceivably have advanced so far and so fast.

To take an example: In comparison with the long history of civilization, it seems only yesterday that the recognition of radioactivity and the precise measurement of this phenomenon made it no longer necessary for us to ponder the mystery of an Earth that according to the physicists' precise laws of a cooling body could not possibly be more than sixty million years old and that yet gave clear geologic and biologic

[1] The present Report is an outgrowth of discussions in the Committee on International Participation early in 1959 and of formal authorization by the Executive Committee at its meeting on November 14, 1959, at which time it was resolved that a brief but comprehensive report of progress in geophysics in the United States during the current triennium be prepared for publication in the Transactions and for presentation to the IUGG at its Twelfth General Assembly in Helsinki.

evidence of an age twenty or more times greater. Furthermore, this same discovery in physical chemistry has led for the first time to methods of great precision for fixing various dates in a geologic as well as in a historical time scale. Again, the long and tedious investigation, beginning only a few decades ago, of the behavior of electromagnetic vibrations was an essential step in the development of a great part of the modern devices for geophysical studies.

And so, in the very recent past a splendid background had been laid for the extraordinary enterprise known as the International Geophysical Year. A keen and widespread interest in Earth science had been aroused; major problems were formulated but still unsolved; and a satisfactory physical and mechanical basis was in hand for the development of instruments with highly improved performance. Initially, the proposed IGY was thought of as a continuation and extension of the First and of the Second Polar Years; but the scope and size of the present world-wide cooperative effect has turned out to have a higher order of magnitude and the program to have a more successful outcome than could easily have been predicted. Geophysics during the current triennium has been dominated by the new venture; the story of recent progress in this field is largely the story of IGY.

In the pages that follow will be found an outline of geophysical progress in the United States of America during the triennium 1957–1960. This Report is scarcely to be considered a summary of progress in geophysics during the three-year period in the United States; for, the extent and variety of the results obtained are such that they could not be truly summarized unless a vastly greater amount of space were available. Rather, the Report presents a brief statement concerning each of several of the more important subjects receiving recent attention.

Inasmuch as geophysics has many branches and sub-branches, the seventy-one topics treated by the separate articles herein by no means cover the whole field adequately, but we find here a varied and stimulating range of subjects such as, for example: the interrelation of gravimetric measurements, astronomical observations, and surface triangulation for obtaining greater certainty as to the size and shape of the Earth; the way in which studies of natural and 'artificial' earthquakes combine with laboratory measurements to clarify our picture of the Earth's interior; the new tools for widening our knowledge of the atmosphere's circulation, extent, and composition at great altitudes, the basis of the variations of the terrestrial magnetic and electric field; the newly discovered belts of intense radiation surrounding the Earth; the mechanics of wave propagation in the oceans and the nature of the solid crust underlying the ocean bottom; new information on the age of certain geologic upheavals, on the composition of the outer layers of our planet, and on the remarkable effects of extreme pressure on rocks and minerals; and the evaluation of the cycle of water movement as bearing on the effects of the transport of major masses of snow and ice.

This Report to IUGG may be thought of as an indication of recent geophysical progress in the United States; as one facet of that friendly and effective cooperation now being carried forward on a world-wide basis in one domain of science; and, perhaps, also as an encouragement of future effort toward a complete solution of the great puzzles of geophysics.

United States National Report, 1957-1959
Twelfth General Assembly
International Union of Geodesy and Geophysics

GEODESY

LEASON H. ADAMS, *Editor*

Geodetic Operations

Compiled by
U. S. COAST AND GEODETIC SURVEY
Washington, D. C.

Preface

This is a report on the geodetic activities of various agencies in the United States covering the period from January 1, 1957, through December 31, 1959, for the Twelfth General Assembly of the International Union of Geodesy and Geophysics to be held at Helsinki in July-August 1960. The material has been arranged in five parts corresponding to the five Sections of the International Association of Geodesy. These parts will be separated and thus serve as individual reports of the five Sections for distribution at a later date by the Central Bureau of the International Geodetic Association.

Triangulation

United States Coast and Geodetic Survey—Considerable progress was made during the 3-year period covered by this report on the extension and further development of the horizontal-control network in the United States. The major part of the effort involved the breakdown of networks with additional arcs and the completion of area or fill nets within the basic framework.

The preliminary surveying and mapping needed for the construction of the Interstate Highway System have required the extension of geodetic surveys along the proposed routes of this highway system. Geodetic surveys that are marked with permanent monuments have been made along several thousand miles of these new superhighways in all parts of the United States.

The last three years have seen an increased use of electronic equipment for the measurement of lengths. Practically every triangulation party is equipped with a Tellurometer so that triangulation, trilateration, or traverse may be observed with the specifications of each individual project determining the type of survey equipment and techniques to be used. Geodimeter Models Nos. 2 and 4 also are used extensively. A Geodimeter party has been in operation almost full time measuring first-order base lines in new nets as well as measuring primary lines of triangulation in older networks, in order to provide adequate length control for some possible future readjustment.

Every Federal agency engaged in geodetic work has some type of electronic computer. An IBM 650 magnetic drum calculator was installed in the Coast and Geodetic Survey in May 1957. This computer is classed as a medium-sized calculator and is found to be adequate for the present needs of the Bureau. The Computing Section is assigned to the Triangulation Branch for administrative direction but the group is asked to assist in the reduction of scientific and engineering problems for all other Divisions of the Bureau as well as care for fiscal and accounting processing.

Because of the availability of a high-speed computer, assistance was given to Martin Ho-

tine and H. H. Brazier of the British Overseas Survey in the application of 3-dimensional techniques for the adjustment of triangulation and trilateration. The experience gained in the development of mathematical procedures and programs for this 3-dimensional method of adjustment has been very helpful in the development of programs for the analytical adjustment of aerotriangulation for the Photogrammetry Division.

The same techniques for the treatment of geodetic and photogrammetric data can be applied to observational data obtained from flash rockets or satellites. At the present time, plans are being made for the launching of a geodetic satellite which may be used by geodesists of all countries, for the extension of their own geodetic networks, connection to islands or outlying areas, and even intercontinental connections. The same data may then be used for a more accurate determination of the size and shape of the Earth.

The program for the reobservations of networks of geodetic control in seismic areas was continued. A more detailed description of this special type of geodetic survey will be found in the report to the International Association of Seismology and Physics of the Earth's Interior.

Ethiopian Geodetic Control Project—Late in 1956 a Joint Commission of the International Cooperation Administration and the Ethiopian Imperial Government requested, through the Secretary of Commerce, that the Coast and Geodetic Survey enter into an agreement for the establishment of a geodetic control system in Ethiopia. The area of interest comprises an extensive unsurveyed and unmapped region of the drainage basin of the Blue Nile River. The cost of this project is to be shared equally by the United States and the Ethiopian Governments. The United States has provided about 12 technicians, including the chief of party, recruited from the ranks of the Coast and Geodetic Survey, while the Ethiopian Government has supplied a working force varying in number from, perhaps, 50 to 75 employees, consisting of civil engineers, trainees, and a variety of supporting personnel.

Arrival of the American technicians in Ethiopia began in the spring of 1957. Some months were spent in reconnaissance and in training personnel; the actual survey operations began late in 1957.

Operations involve first-order triangulation, including base lines, first-order leveling, and first-order astronomic observations. Connections were made to the geodetic surveys in the Sudan and in this way the Ethiopian triangulation net was placed on the African Datum which, in turn, is tied to the European Datum.

United States Geological Survey—The topographic mapping activities of the Geological Survey require surveys to provide a geodetic-control framework. Most mapping needs are met by extending third-order control from the basic network of first- and second-order control covering the country.

During this three-year period (1957–59), control surveys were conducted in the United States, Alaska, Hawaii, and the Virgin Islands. These surveys consisted of triangulation, traverse in which distances were measured electronically and angles by theodolite, transit-and-tape traverse, and leveling. Approximately 3800 new triangulation stations were established. About 4500 miles of Tellurometer traverse and 16,400 miles of transit-and-tape traverse were run.

Permanent marks were placed at the primary triangulation stations, along the traverse lines at 2- to 4-mile intervals, and at about the same intervals along lines of leveling. Positions and elevations for the monuments, and for other identifiable intermediate points, are published in separate lists covering 15-minute quadrangles. Besides providing a framework of control for the mapping, the control surveys of the Geological Survey are used extensively by other Federal, State, and private organizations wherever third-order control satisfies the needs of local projects.

The Bureau participated in scientific activities in Antarctica throughout the 3-year period. One engineer accompanied several geophysical-traverse parties as navigator and determined geographic positions along the routes by astronomic observations made with a theodolite. The positions of nunataks and mountain peaks visible from the routes were determined by triangulation from measured bases. Two additional engineers were assigned to the work in 1959. They determined positions and elevations along geophysical-traverse routes and positions

of identifiable points for the control of photogrammetric mapping.

The development of new field techniques, the use of improved instruments, and the increased speed and ease of transporting men and equipment by air in difficult terrain have facilitated field operations. Helicopters were used almost exclusively in Alaska to transport men and equipment between control points. Their use was also increased in remote areas within the United States. This rapid transportation enabled observers to arrive fresh at working sites and take full advantage of favorable observing conditions.

The Tellurometer, an instrument measuring distances by timing the round trip transit of radio microwaves, was tested and found to yield accurate results and to be economical for field use. Thirty Tellurometer units are now used on control surveys consisting primarily of traverses in which angles are measured with one-second theodolites. A new flashing signal light has been developed to insure certainty in pointing.

Programs for certain geodetic computations were coded for the Datatron 205 electronic computer. Considerable work was done in the computation of transit-tape traverse and the conversion of geographic coordinates to rectangular coordinates on the State plane-coordinate systems. With the recent acquisition of a higher-speed computer, it became necessary to recode these programs and the work is now nearing completion.

United States Army Map Service—In Iran, the United States Army Map Service cooperated with the Iranian Government in establishing first- and second-order triangulation in Iran. The first-order triangulation consists of a chain of quadrilaterals with five geodimeter bases and seven Laplace stations. It extends from the Turkish border in the northwest to the Pakistan border in the southeast, and is connected to the first-order networks of Turkey and Pakistan (Survey of India triangulation).

Astronomic observations of latitude and longitude were made along this chain at about 30-mile intervals to provide a geoidal section which permits the extension of the computation of geoidal heights from Europe into India (see under Section: *Geoid Investigations*).

In Libya, the 329th Engineer Detachment (Geodetic Survey), a special foreign activity of the Army Map Service, conducted field surveys in Libya during 1957–1959 to extend a first-order triangulation arc from Tunisia to Egypt, for the purpose of establishing horizontal and vertical mapping control and to perform field classification of photography of the mapping area. This assignment requires the establishment of survey control for the photogrammetric mapping of 41,200 sq mi at 1/50,000 scale, and 55,800 sq mi at 1/250,000 scale.

Inter-American Geodetic Survey—During the calendar years 1957–1959, the Inter-American Geodetic Survey, in collaboration with 17 Latin American countries, established 750 first- and second-order triangulation stations. This control was established in widely scattered areas and is a continuation of a long-range plan to establish a strong geodetic network connecting North and South America.

Twenty-five first-order base lines were measured by Geodimeter during the reporting period. These base lines were measured at elevations ranging from sea level to 4500 meters, encountering temperatures from −5° to +29° centigrade and with humidities of 42 to 99% with no adverse effects.

United States Lake Survey—The basic horizontal geodetic control established by the United States Lake Survey consists of networks of first-order triangulation bordering the Great Lakes. These basic networks have been extended by second- and lower-order triangulation and by traverse in many areas to provide more closely spaced and more conveniently located stations for the hydrographic surveys of the lakes. The Lake Survey control network has been adjusted into the United States Coast and Geodetic Survey horizontal-control network of the country, and forms the framework of the navigation charts of the Great Lakes and their outflow rivers.

The only extension of the control network that is now required is the small amount made in connection with current hydrographic surveys. During the period 1957–1959, 33 miles of Tellurometer traverse were run along the easterly end of Lake Ontario, and five permanently marked stations were established in the reach. In addition, about 44 miles of stadia traverse were run in the same area.

Seven miles of stadia traverse, in various

short lines, were run along Lake St. Lawrence on the St. Lawrence River to establish traverse stations close to the river for control of a survey of the power pool of the new St. Lawrence River Power Project.

On Lake Huron, 120 miles of stadia traverse were run, and permanently marked traverse stations were established at about two-mile intervals.

The control work on Lake Ontario and on Lake Huron was in connection with resurveys of the shoal coastal waters that will be used eventually to produce special charts for small-boat navigation.

During the period 1957–1959, the Lake Survey also completed the program of adjustment of all second- and third-order triangulation into the nationwide horizontal control network of the United States Coast and Geodetic Survey.

United States Air Force—Geodetic operations on a global basis were conducted by the United States Air Force during the years 1957–1959, using the HIRAN trilateration system of surveying. A small network connecting certain Brazilian islands to the mainland was completed during the previous reporting period but was not included in that report.

Other projects completed or nearing completion at the close of this reporting period include the following:

In the Marshall Islands Survey, the long-range capability of the Hiran system permitted the formation of a local datum for this island group. By orienting the Hiran net with a Tellurometer traverse between two Hiran stations and with an observed astronomic azimuth over a relatively long line, and by referencing the net to gravity-corrected astronomic positions, the established geographic positions of the Hiran stations should be relatively close to true values. In addition to the nine Hiran stations positioned, thirteen secondary control points were established.

In the Cuba-Central America Tie, a Hiran network closing the continuous loop of triangulation around the Gulf of Mexico by linking Cuba and Jamaica with British Honduras, Guatemala, and Honduras was completed in December 1959. Secondary control points were established at points on Little Cayman and Cayman Brac.

Formosa-Ryukyu Tie, a network that is composed of 12 Hiran ground station sites and 35 lines, connects Formosa with six of the Ryukyu islands and the Dacto islands and is nearly completed as of this reporting date.

Preliminary field reconnaissance is presently under way for a major Hiran project along the northeast coast of South America, connecting the existing triangulation in Venezuela with the triangulation near Recife, Brazil.

United States Navy Hydrographic Office—During the period covered by this report the Hydrographic Office conducted local triangulation surveys for the control of hydrographic surveying at Subic Bay, Philippine Islands, Kwajalein Island, and various locations in Labrador, Newfoundland, Canada, and the West Indies.

Precise Leveling

United States Coast and Geodetic Survey—During the period from January 1, 1957, to December 31, 1959, the Coast and Geodetic Survey undertook leveling along 11,583 miles of first-order and 16,282 miles of second-order lines. The total leveling in the net as of December 31, 1959, is 177,600 miles of first-order and 268,200 miles of second-order which total 445,800 miles of first- and second-order leveling along which 380,000 bench marks have been leveled over.

First-order lines are spaced at approximately 100-mile intervals with second-order lines at 25-mile intervals. Within the 25-mile loops, 'area' leveling is being run consisting of second-order lines spaced from 5 to 10 miles apart. Releveling has been undertaken for practically all of the first-order lines established prior to 1916 which is the date the invar rods came into use.

New leveling is adjusted to the basic net. However, where extensive releveling or new leveling indicates changes in elevations, it is often necessary to readjust portions of the basic net.

Three main parties have been leveling continuously during this period, one on the East Coast, one in the Central States, and one on the West Coast. Each of these field parties had two units during the winter months and usually three units during the summer months.

The Galveston-Houston, Texas area was releveled during the winter of 1958-1959 to determine the magnitude and extent of settlement. Releveling of this net of lines is scheduled at 5-year intervals.

In the San Joaquin Valley of California, a releveling of certain portions has been scheduled at 2-year intervals. This releveling is being done at the request of the Inter-Agency Committee on Land Subsidence in the San Joaquin Valley for the purpose of studying the rate of settlement. Lines are extended to provide as many anchors in granite as possible.

A line of leveling was rerun in the vicinity of Hebgen Dam, Montana, following the earthquake of August 17, 1959, in that region, to determine the earth displacement. The maximum settlement measured was 18.86 feet.

Metal posts with an attached aluminum sign bearing the legend *Witness post—Please do not disturb nearby survey marker* are now placed near our bench marks.

United States Geological Survey—During the period of this report (1957-59), the Geological Survey ran 43,100 miles of leveling, mostly of third-order accuracy. About 500 miles of double-run, second-order leveling were extended in areas where the basic network is sparse. Monumented bench marks were established at intervals of 2 to 3 miles along the lines.

About 75% of the leveling was done with automatic pendulum-type levels which gave satisfactory third-order results. Most of the networks were adjusted on the Geological Survey Electrical Survey Net Adjuster, an analog computer which yields results equivalent to a rigid least-squares adjustment but saves time.

The Johnson elevation meter, a self-propelled vehicle for determining elevations, was used on a number of projects to provide fourth-order vertical control for photogrammetric mapping. About 6000 miles of leveling were completed with this equipment. The instrument integrates electrically the product of the distance measured by a fifth wheel, and the sine of the slope angle of the road surface, measured by a pendulum. Where an adequate network of roads exists in the area to be mapped, elevations of sufficient accuracy for supplemental control are obtained much faster than by any of the conventional methods of fourth-order leveling. The Geological Survey is purchasing two new elevation meters with transistorized electronic circuitry to further speed field operations in supplemental control.

Inter-American Geodetic Survey—The Inter-American Geodetic Survey has continued to assist Latin American countries in development of a network of geodetic leveling. The work has included determination of mean sea level by tide-gaging methods. During the period covered by this report 24,280 kilometers of first-order levels have been run. Since 1946, when this collaborative program began, a total of 128,000 kilometers of first-order line have been accomplished and the elevations determined for more than 65,000 bench marks. The first-order network is continuous from the United States to Chile with the exception of a break in Panama where there are no transportation facilities by land through the Darien region adjacent to Colombia. From Chile the leveling extends eastward through Bolivia and Brazil to the Atlantic Coast.

United States Lake Survey—The vertical geodetic control established by the United States Lake Survey consists of groups of bench marks in 106 harbors on the Great Lakes and 500 miles of level lines of special first-order accuracy along the outflow rivers of the lakes. Elevations of the bench marks are listed on the United States Lake Survey 1935 Datum.

This datum was established in the following manner: In 1903, the United States Coast and Geodetic Survey made an adjustment without applying the orthometric correction, based on level lines and tide gage records in the United States east of the Mississippi River. The elevations of bench marks on the Great Lakes included in this adjustment were adopted by the Lake Survey and were designated as being on the United States Lake Survey 1903 Datum. This datum was extended to all major harbors on the Great Lakes and along the outflow rivers by the Lake Survey and the Canadian Hydrographic Service.

By 1935, differential movement of the Earth's crust was causing gages on the same lake to show appreciable differences in water-surface elevations, requiring the establishment of a new datum. A control point was chosen on each lake: Oswego, New York, on Lake Ontario,

Cleveland, Ohio, on Lake Erie, Harbor Beach, Michigan, on Lake Michigan-Huron, and Point Iroquois, Michigan, on Lake Superior; and the bench mark elevations at the control points were held as given on the 1903 Datum except for Point Iroquois, where the elevations were derived from Harbor Beach by water level transfer and levels of 1934 between Lake Huron and Lake Superior. Bench mark elevations at other sites on the United States side of the Great Lakes were computed from these control points by water-level transfers supplemented by local leveling and the resulting elevations were said to be on the United States Lake Survey 1935 Datum. In other words, the elevations derived were the elevations of the bench marks in 1935 with respect to their particular control point.

At the present time, the Lake Survey is collaborating with three Canadian agencies, the Department of Northern Affairs and National Resources, the Department of Mines and Technical Surveys, and the Department of Transport, in the establishment of a new datum that will be called the International Great Lakes Datum, 1955. This datum will be based upon the mean water level at the outlet of the Great Lakes system in the Gulf of St. Lawrence; specifically, upon the mean water level as measured by the tide gage at Father Point, Quebec. The dynamic numbers that will be determined for the bench marks will be adopted as their elevations on the new datum. The Chief of Engineers, United States Army, has approved the adoption of the new datum in the United States and early use of it on Lake Ontario and the St. Lawrence River by both countries is now under consideration.

The equipment employed by the Lake Survey in leveling of special first-order accuracy consists of the Zeiss Opton self-leveling level and United States Coast and Geodetic Survey rods. The method of observing consists of direct rod readings to the nearest millimeter of three cross hairs on both the backsight and foresight, for which a mean is computed to four decimal places in meters. Lines are run in both directions until forward and backward runs are obtained that agree within the limit of 3.0 mm $\sqrt{K}$, where K is the length of the line in kilometers.

Transfer of elevations by water levels is made between harbors on the same lake by comparisons of gage records at the harbors involved. Only the records of the months June through September, when the lakes are not influenced by wind and barometric disturbances to any major degree, are used. Transfer to a given point on a lake is made from two or more gage sites where elevations have been established previously.

At the sites of bench mark groups where water level gages are not maintained continuously, temporary gages are installed on the average of once every ten years to check the stability of the groups and the rates of crustal movement of the Earth. In addition, all of the bench marks are recovered triennially and second-order levels are run between the bench marks of each group to check their relative stability. Bench marks along the outflow rivers are recovered periodically and the level lines are rerun for a similar purpose. Bench marks established and maintained by the Lake Survey, in addition to being used for control of hydrographic surveys for the navigation charts and for study of the hydraulics of the Great Lakes, are used to control the federal navigation projects by other Corps of Engineer Districts. They are also used by many other government agencies and by a number of industries concerned with the levels of the lakes and rivers.

During the period 1957–1959, the Lake Survey ran 436 miles of special first-order levels, involving 829 bench marks. Most of these levels will be used in connection with the establishment of the International Great Lakes Datum, 1955.

The Lake Survey method of observing long over-water distances is as follows: The level is set up near the bench mark at one end of the over-water line and the rod is read on the near bench mark. A target is then set on the rod on the bench mark at the other end of the over-water line. The target is moved off setting and then reset on the far bench mark. This resetting is repeated at least eight more times. Extra settings are made to replace any settings that appear to be markedly different from the average. After the series of rod settings on the far bench mark is completed, a check reading is taken on the rod on the near bench mark. The

level is then moved to the other end of the over-water line and the foregoing procedure repeated. Following this, the level is moved to another location near the same bench mark and the procedure repeated. The level is then moved back to the end of the over-water line where it was originally placed, is set up near the bench mark but not at the original set-up position, and the procedure is run a fourth time.

Geodetic Astronomy

Observations of latitude, longitude, and azimuth in the United States and other areas were continued throughout the reporting period. These data were employed in control of triangulation arcs, deflection of the vertical determinations, detection of crustal movements in earthquake areas, and for other special purposes.

A total of 73 first-order latitude and longitude stations were observed. These included 19 stations for control of personal equation in second-order position observations on the 35th parallel geoid profile, and five Laplace azimuth stations on the Blue Nile triangulation project in Ethiopia. A large number of first-order astronomic positions were observed in the United States and other areas in connection with military requirements. A total of 41 astronomic azimuths were observed for triangulation control in the United States, Hawaii, Ascension Island, and Ethiopia.

Conventional meridian transits of the Bamberg and Wild T-4 types are employed in first-order position determination. Latitudes are determined from 15 or 20 Horrebow-Talcott star pairs. Longitudes are based on 5 to 7 sets of about 6 stars each, with WWV time signals recorded on drum chronographs and compared with mechanical chronometers at approximate 1-hour intervals.

In 1958 new equipment was adopted for the recording of first-order longitude observations, resulting in simpler operation, better performance, and reduction in weight. An electric-driven drum chronograph replaced the weight-driven type, reducing total shipping weight from 150 pounds to 15 pounds per unit. The vacuum-tube amplifier was replaced by a more compact transistor amplifier-filter having about 90% less battery drain and greatly improved response and stability. The new equipment performed reliably on five first-order stations in 1959 in Ethiopia, where WWV time signals were recorded with little or no difficulty.

Astronomic azimuths are usually observed with Wild T-3 theodolites, except that in high latitudes the Wild T-4 theodolite is employed. Close circumpolar stars at any hour angle are observed where possible. In equatorial latitudes, east and west stars are observed near elongation in the altitude range between 8 and 22°.

Second-order latitudes and longitudes were observed at 133 stations on the 35th parallel geoid profile and at 21 other locations. Wild T-3 theodolites were employed, observing four east-west star pairs for longitude and Polaris with a matching south star for latitude. Personal equations were determined at approximate five-station intervals. The times of star pointings were estimated by the observer directly from continuously audible WWV one-second time signal pulses. Average internal probable errors of about 0.4 seconds of arc in each component were obtained with the second-order procedure. Considering slight variations in personal equation of the observer, an actual probable error of about 0.8 second of arc is indicated for longitudes observed by fully experienced personnel.

Variation of Latitude

Two of the five northern-hemisphere International Latitude Service observatories on the 39th parallel were maintained in continuous operation by the Coast and Geodetic Survey at Gaithersburg, Maryland, and Ukiah, California. At Gaithersburg, 8938 star pairs were observed on 773 nights, with complete observations on 218 nights. At Ukiah, 11,532 star pairs were observed on 726 nights with complete observations on 505 nights.

IGY Longitude and Latitude Observations

In early 1958 the Coast and Geodetic Survey established a temporary astronomic observatory at Honolulu, Hawaii, in cooperation with the IGY Longitude and Latitude program. The program involved continuous nightly observations with a Danjon impersonal astrolabe and a Markowitz dual-rate moon camera. The astrolabe position measurement program will aid

in the detection of small intercontinental drifts and in studies of variation of the Earth's rotation axis. The Moon-camera data will be employed to determine the Moon's position among the stars in connection with investigations of uniform time and new geodetic positioning applications. Time control was provided by a quartz clock monitored by time signals from WWVH on the island of Maui, Hawaii. Astrolabe observations were automatically recorded on tapes fed through a digital printing chronograph. At the conclusion of the observing period in December 1959 essentially complete astrolabe data had been observed on 362 nights and a total of 1,280 moon-camera plates had been obtained.

United States Army Map Service—Since January 1958 the United States Army Map Service has carried on radio interferometric tracking of artificial satellites at two stations on Pacific islands. Thus far, observations have been made on Luzon, Kwajalein, Guam, Wake, Ponape, and Samoa. At each station, three pairs of Mark II Minitrack antennas on 330-meter baselines were employed to receive the 108-megacycle signals transmitted by the satellites. The antennas were oriented by the tracking of radio stars; this orientation has proved to be the principal cause of inaccuracy in the system, and arrangements are being made to orient by the tracking of aircraft.

Occultation observations by photo-electric cells to obtain differences in latitude and longitude have been continued on Japan, the Ryukyus, the Philippines, Marcus, the Marianas, the Carolines, the Marshalls, Wake, Midway, Hawaii, and California. Up to June 30, 1959, 71 pairs had been successfully observed by United States Army Map Service, Far East. Accuracy of preliminary results is ±200 meters in each coordinate. Final results are not yet computed, but are awaiting completion of lunar limb mapping and an improved lunar ephemeris by the United States Naval Observatory.

Inter-American Geodetic Survey—Fifty-eight stations were occupied during the reporting period for observations of latitude, longitude, and azimuth. The average probable errors are: Latitude ±0.″06; Longitude ±0.″06; Azimuth ±0.″19.

United States Air Force—One first-order astronomical station was observed in Columbus at the McMillin Observatory in order to provide a precise value for computation of the astro-gravimetric deflections in that area.

First-order astronomic positions were observed at several HIRAN locations in the Cuba-Central American Trilateration Network. The computations for this work were performed by the Inter-American Geodetic Survey.

United States Navy Hydrographic Office—During the period covered by this report first-order astronomic observations were made at Bermuda, Atol das Rocas, and Clipperton Island.

Gravity Observations and Reductions

United States Coast and Geodetic Survey—Gravimetric observations of the Coast and Geodetic Survey were accomplished entirely with gravity meters during the 1957–1959 period.

Area gravity surveys were continued in Minnesota and adjoining States, involving a total area of approximately 60,000 sq mi and completing a north-south belt of gravity coverage about six degrees in width extending from the Gulf of Mexico to the Canadian boundary. Free-air and simple Bouguer anomalies are determined for area coverage stations, employing IBM equipment for computing and listing.

Several gravity meter traverses were measured to develop the basic control network and provide more accurate calibration standards. The first of these was a connection between the national bases at Washington, D. C., and Ottawa, Canada, with an additional tie to Idlewild Airport, New York City, one of the primary stations in the transAtlantic gravity network. Early in 1957 the midcontinent gravity calibration line was traversed between Beloit, Kansas, and Brownsville, Texas. During this operation auxiliary stations were established in the vicinity of each control point to provide easier recovery and guard against possible destruction of station marks. An additional gravity traverse, consisting of 35 stations, was established between the national base in Washington, D. C., and Key West, Florida, for future gravity control along the East Coast. During this operation, approximately 40 pendulum stations previously established in southern Florida were connected to the new network.

The gravity traverse between the national bases at Washington, D. C., and Ottawa, Can-

ada, was rerun in November 1957 to strengthen datum and calibration comparison between the American and Canadian systems. During this operation a connection was made to the Montreal International Airport, the western terminus of a recently completed transAtlantic gravity meter tie. Early in 1958 operations were resumed on the East Coast base network between Washington, D. C., and Key West, Florida. About 165 pendulum stations were recovered and connected to the network. Wherever possible, nearby permanent points of known elevation were tied to the pendulum stations to aid in future recovery.

Special gravity measurements were made at instrument test facilities of the Martin Company in Denver, Colorado, and the Sperry-Farragut Company in Bristol, Tennessee.

A new gravity meter calibration base was established in the vicinity of Sperryville, Virginia. This new base, consisting of two stations having a gravity difference of about 74 milligals, provides better calibration data than the longer base previously employed.

Beginning in November 1958 a gravity base traverse was run between Bellingham, Washington, and San Diego, California, comprising 68 primary stations and numerous auxiliary points established for convenience in future recovery. The traverse was connected to the midcontinent gravity base by direct air transport over the lines: Seattle, Washington, to Fargo, North Dakota; San Francisco, California, to Kansas City, Missouri; and San Diego, California, to Dallas, Texas. Improved gravity values were determined for 51 pendulum stations along the West Coast.

A special gravity survey was completed at Vandenberg Air Force Base and the U. S. Navy Missile Facility near Pt. Arguello, California, in connection with rocket launching requirements. About 140 stations were established at a rectangular spacing of approximately 3 miles.

United States Geological Survey—Regional gravity surveys in parts of 18 States have been conducted by the Geological Survey in connection with geologic investigations. Emphasis has been placed on areas in the Pacific Northwest, Maine, and Alaska, where natural resources are relatively undeveloped. Gravity measurements were also made in Nevada, eastern California, southeastern Utah, northern New Mexico, eastern Kentucky, and the Black Hills of South Dakota. About 23,000 gravity stations were occupied during 1957–1959 in these various areas, which total about 210,000 square miles. The station spacing varies from one-half mile for semidetailed investigations to as much as 7 miles for regional work. These data are being used primarily to locate and trace geologic structures at depth and to obtain information on the major rock masses.

All gravity observations have been tied to G. P. Woollard's airport network in the United States or to U. S. Coast and Geodetic Survey pendulum stations. Standard Bouguer reductions for an assumed density of 2.67 g/ cm^3 have been made for all stations and many stations have been reduced for several additional densities which apply to local areas. The Bouguer reductions include curvature and terrain corrections through Hayford Zone O in areas where these corrections are significant to the interpretation of local anomalies. Airy-Heiskanen (T = 30 km) anomalies have been computed for about 150 stations in east-central California in connection with a study of the Sierra Nevada Mountains.

The computations of free-air and Bouguer anomalies including curvature and terrain corrections have been programmed for the Geological Survey's Datatron equipment and the program has been in operation since August 1, 1959.

The Geological Survey has agreed to publish and distribute free-air and Bouguer gravity maps of the United States in cooperation with the American Geophysical Union's Committee for the Geological and Geophysical Study of the Continents. The gravity maps are being compiled by a group of editors under the direction of Woollard.

United States Army Map Service—In July 1959 the United States Army Map Service obtained two LaCoste-Romberg model-G gravity meters, which have been used on field projects in Iran, Greenland, Taiwan, and the Ryukyus.

Inter-American Geodetic Survey—The Inter-American Geodetic Survey has cooperated in establishing approximately 12,000 gravity stations in Mexico and Central and South America.

Gravity traverses along main first-order level lines have been completed from Santiago, Chile,

to northern Colombia, and along the transcontinental level line from Arica, Chila, to Rio de Janeiro, Brazil. Free-air anomalies have been compiled for the observations in Chile, Bolivia, and Ecuador.

A gravity survey along existing level lines in the Dominican Republic has been completed and free-air anomalies compiled.

The gravity coverage of the La Canoa Datum in Venezuela has been systematically extended to a radius of about 130 km. An extensive area of large negative free-air anomalies extending from Trinidad to central Venezuela has been discovered.

Cooperative surveys for general gravity coverage are being continued in Brazil, Bolivia, Peru, Colombia, Venezuela, Honduras, Guatemala, British Honduras, Mexico, Cuba, and Jamaica.

United States Air Force—Under sponsorship of Air Force Cambridge Research Center the group under G. P. Woollard carried out observations with the Gulf quartz pendulums (M set) throughout Alaska, South America, the Far East, Australasia, and Antarctica. Approximately 30 new stations were occupied.

In order to provide an interim system of nationwide bases for control of gravity surveys, the Air Force Cambridge Research Center sponsored the establishment of a network of approximately 130 gravity stations at airports throughout the United States. Measurements were made with two high-range Worden meters by the University of Wisconsin group under Woollard. Recovery of many of these airport stations in the Coast and Geodetic Survey base net program indicates an average agreement of 0.3 milligal.

Under sponsorship of Air Force Cambridge Research Center the group under Woollard completed in 1958 a series of gravity meter observations in Alaska primarily to extend the coverage of gravity bases. The work comprised observations at 513 sites of which approximately one-third are located at airports and the remainder are located on traverses at a 5- to 10-mile station spacing.

The first known measurements of gravity in a flying aircraft were made in a test conducted by Air Force Cambridge Research Center on November 6 and 7, 1958, at Edwards Air Force Base, California. A LaCoste-Romberg surface ship gravity meter was mounted in a KC-135 jet tanker and flights were made in north, south, and west directions at altitudes of 20,000 and 30,000 feet. Navigational data were provided by a Doppler system in the aircraft, and ground tracking facilities. In this initial test accuracy of the order of ten milligals was indicated by comparison with gravity extrapolated from the ground surface.

A joint United States Air Force—Inter-American Geodetic Survey effort established a gravity reference station network throughout the project area of the Cuba-Central American Survey. All the stations are tied to the international pendulum station located at Albrook AFB, Canal Zone. Gravity meters were used to measure at least two gravity differences between each two successive reference stations of the network loops. Preliminary computations indicate loop closures of less than 0.2 mgal; however, final computations and adjustments have not been completed at the time of this report. IAGS personnel acquired additional detail data in the vicinity of each station.

Other Organizations—The Institute of Geophysics, University of California at Los Angeles, reports very favorable comparative tests of the LaCoste-Romberg surface ship meter with 14 previously established submarine stations off southern California, and with 27 under-water meter stations. The surface ship meter has also been employed recently in a survey of the Gulf of California in which continuous profiles across the Gulf were established at 10-mile intervals.

Recent sea gravity activities of the Columbia University group under J. L. Worzel include measurements on H. M. S. *Telemachus* at 130 stations in the vicinity of Australia and New Zealand in 1956; on U. S. S. *Grenadier* (SS *525*) at 29 stations in the western Atlantic; and surface ship measurements taken on U. S. S. *Compass Island* along a track from New York through the Straits of Gibraltar to the western Mediterranean. Other extensive tests on surface ship gravity measurements were carried out by this group.

Under the IGY Antarctic program gravity bases were established at 11 stations, the network being controlled by pendulum ties from McMurdo to Christchurch and Melbourne, and by gravity meter ties from Ellsworth to the

pendulum stations at Buenos Aires and Punta Arenas, South America. Approximately 4100 miles of gravity traverse were run, with stations spaced at 5- to 15-mile intervals. Gravity data from the program are being processed by the Antarctic Gravity and Seismological Data Reduction Center at the University of Wisconsin.

The Woolard group continued its worldwide program of gravity meter observations. New work included ties between the various U. S. Antarctic bases and connection to the British Base (Fuchs party), New Zealand Base (Hallett), and Russian Base (Mirny). Numerous observations were made in Central and South America, in Australia, and along the areas of pendulum operations.

Geoid Investigations

United States Coast and Geodetic Survey—In 1956 work was begun on the determination of a precise geoid profile extending over the total width of the United States along the 35th parallel. Astro-geodetic stations were established at an average spacing of about 14 miles. Second-order astronomic positions were determined at each station, supplemented by first-order positions at intervals of four or five stations to provide frequent checks of observer personal equation. The methods employed gave an accuracy of slightly better than one second of arc in the prime-vertical deflections, which are critical in construction of the profile. At the end of 1959, 147 stations had been determined over the section of approximately 2100 miles extending from the Atlantic Ocean to central Arizona. The profile will be completed early in 1960 by the addition of 30 more stations in Arizona and California. A preliminary study has been made of the available data based on the Clarke Spheroid of 1866, North American 1927 datum. From an assumed geoid height of zero at the Atlantic coast, the geoid rises gradually to a maximum of 12 meters in western Tennessee, drops gradually, then undulates moderately over a range of plus one to plus six meters until the line reaches western New Mexico. From this point the geoid drops to about minus four meters in central Arizona.

The problem of determining anomalous components of the Earth's gravity field at altitudes of several hundred miles was investigated, working procedures developed, and values determined for various typical rocket trajectories. The analysis was based on the Stokes surface coating as derived from sea level gravity anomalies and geoid height data.

A geodetic datum position was determined for Ascension Island, based on first-order astronomic positions and gravimetric deflections of the vertical at three stations on the island.

United States Army Map Service—The United States Army Map Service extended its computation of geoid heights by astro-geodetic data into India, Japan and Korea, around the Caribbean, and into Brazil.

A statistical and harmonic analysis of free-air gravity anomalies and topography was made. Markov analysis was applied to obtain a world-wide estimate of gravity, and autocorrelation analysis was applied to obtain errors of representation in both gravimetric and astro-geodetic data.

Secular motions of the node and perigee of the *Vanguard I* satellite were analyzed to obtain a new estimate of the flattening: 1/298.3.

The astro-geodetic geoid, world-wide gravity anomaly estimates, secular and long-period motions of the *Vanguard I* satellite (as analyzed by the National Aeronautics and Space Administration) and the North Atlantic HIRAN survey connection (observed by the United States Air Force) were combined in a generalization of least squares applicable to correlated data to obtain: shifts for the North American, European, and Tokyo Datums; ellipsoid and standard gravity formula parameters; and an expression of the geoid in spherical harmonics to the eigth degree. The standard deviations obtained were ±8 meters in equatorial radius, ±0.01 in the reciprocal of flattening, ±0.001 cm/sec^2 in equatorial gravity, ±25 meters (spherical) for the European Datum, ±27 meters for the North American Datum, and ±62 meters for the Tokyo Datum.

United States Air Force—In 1957 the United States Air Force contracted for the computations of gravimetric deflection components and geoid heights at 35 selected first-order astro-geodetic stations; 11 in the United States, 13

in Europe, eight in Japan, and three in Manchuria. Available worldwide gravity coverage was used and the computations were based on free-air anomalies computed by the use of the International Gravity Formula. Zero free-air anomalies were assumed for the gravimetrically unsurveyed sea areas. In 1959 these gravimetric quantities were recomputed on the basis of a different gravity formula with a changed flattening term and under the assumption of zero isostatic anomalies for the gravimetrically unsurveyed areas.

Gravimetric quantities available were utilized in an attempt to unify the geodetic datums of the different continents. The first reduction of the European, North American, and Tokyo Datums into a common Earth-centered geodetic system was accomplished in March 1958 and another attempt to improve the *World Geodetic System* was published in August 1959. The USAF 1959 solution, together with the work accomplished by the Army Map Service, constitutes the Department of Defense World Geodetic System which will be adopted in 1960.

Other Activities

United States Air Force—In cooperation with the British Air Ministry and the Military Survey, a composite USAF—USC&GS team accomplished limited geodetic surveys in England from April 1958 through June 1959. Surveys for the THOR program were carried out in Lincoln, Norfolk, Cambridge, and Suffolk Counties. The THOR program subsequent to June 1959 is being carried on by the British Air Ministry and Military Survey.

USAF missile survey requirements in the United States were assigned to USC&GS for accomplishment.

American Geophysical Union Committee on Geodetic Applications of Artificial Satellites—Because of interest shown in some of the discussions at the 11th General Assembly of the IUGG (Toronto 1957) an informal committee was organized within the Section of Geodesy, AGU, for the purpose of studying geodetic applications of artificial satellites. The committee has served primarily for the exchange of ideas and opinions rather than as a policymaking or advisory group.

A preliminary meeting was held at the Army Map Service in December 1957 at which time the broad aspects of the geodetic satellite program were discussed. The next meeting of the group was in Boston in March 1958 at the invitation of the Air Force Cambridge Research Center. Later that year in May at the time of the annual meeting of the AGU, several members of the committee met again. A summary report was prepared after that May meeting so that printed material might be available for submission to agencies or individuals interested in the geodetic satellite program.

When the Panel on Geodesy, under the Space Science Board, was organized, several members of this AGU committee were asked to serve. The committee itself, because of its informal organization, has not met regularly but the individuals who participated in these earlier meetings continue to exchange ideas either by correspondence or in small group discussions.

The basic concepts developed within this group for a geodetic satellite program were forwarded to the National Aeronautics and Space Administration and are being used by that agency in the development of its program.

Important Geodetic Meetings, 1957–1959—During the period of this report, several important meetings of geodesists were held in the United States, in addition to the Annual Meeting of the Section of Geodesy of the AGU. Among these the more important are:

Cambridge, Mass., December 1–2, 1958—A Conference on Contemporary Geodesy was sponsored by the Section of Geodesy, American Geophysical Union, in cooperation with the Harvard University and Smithsonian Astrophysical Observatory. The Proceedings of this conference were published as Monograph No. 4 of the American Geophysical Union.

Bedford, Mass., December 3–4, 1958—A Seminar on Military Geodesy was sponsored by the U. S. Air Force Cambridge Research Center.

Washington, D. C., May 5–12, 1959—A Symposium on Electronic Distance-Measuring Equipment was sponsored by the International Association of Geodesy at which the Section of Geodesy, American Geospyhical Union, was host.

Washington, D. C., August 6–7, 1959—A Con-

ference on Military Requirements for Geodesy was sponsored by the U. S. Army Map Service.

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United States National Report, 1957-1960
Twelfth General Assembly
International Union of Geodesy and Geophysics

SEISMOLOGY AND PHYSICS OF THE EARTH'S INTERIOR
(including Tectonophysics)

LEASON H. ADAMS, *Editor*

Seismic Instruments

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Modification of the recording system of the Benioff extensometer and the development of the Press-Ewing seismograph has focused attention on the rewards of such instruments so far as recording new types of waves are concerned. Under IGY auspices two new strain systems were installed in South America and Press-Ewing instruments were placed at many stations throughout the world, including Antarctica.

There is much interest in extending even further the long-period response of seismographs as well as raising their magnification by restricting response to microseisms. A new recording system was developed for the strain seismograph in order to record the long waves better. With this system the recording amplitude is substantially flat for ground displacements for periods of several hundred seconds and falls to half amplitudes at 1000 sec.

The use of passive resistance-capacitance networks having equivalent response characteristics of galvanometers affords a convenient means of extending galvanometer periods from 75 sec to 10 min. An 8-minute mechanical galvanometer has been separately developed. As much as tenfold increase in pendulum periods have been obtained by using shunt capacitances. Thus a 275-sec pendulum period has been achieved with the mechanical stability of a 30-sec pendulum. The incorporation of these galvanometers with pendulums and seismographs having velocity and displacement transducers represents a major advance in long-period seismometry.

Sharp rejection filters for removing the microseismic band have been incorporated with long period seismographs permitting operation at high magnifications. Remarkable records have been made which demonstrate that a very small network of such instruments could record surface waves from most earthquakes with magnitudes greater than 4.5.

Feasibility studies on the use of arrays of seismographs, recording systems with digital output, unmanned telemetering seismographs, sea bottom seismographs and lunar seismographs were carried out.

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Changes in United States Seismograph Stations and Equipment 1957–1960

Compiled by L. M. MURPHY

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Stations	Remarks
UNIVERSITY OF CALIFORNIA	
Arcata, Calif.	Sprengnether Z, T_0 = 2 sec, T_g = 2 sec, added to existing installation June 3, 1959.
Berkeley, Calif.	New strong-motion 100 X Torsion, N, E, T = 0.8 sec, added Oct. 9, 1957. Three Press-Ewing long-period N, E, Z, T_0 = 30 sec, T_g = 90 sec, added May 1, 1959. Discontinued operation of mechanical seismographs Oct. 27, 1959: Bosch-Omori, 100 kilogram N, E, T = 12 sec.; Wiechert 80 kilogram Z, T = 4 sec. (Operation of these instruments commenced Oct. 30, 1910.)
Fallon, Nev.	Discontinued Sprengnether seismograph operation June 1957.
Ruth, Nev.	New station (Oct. 4, 1959) in cooperation with Seismological Laboratory, Pasadena, and Kennecott Copper Corp. 39°14′N, 114°59′W, elevation 2270 m. *Temporary equipment* (until January 3, 1960): Benioff portable (transducer type) E, T_0 = 1 sec, T_g = 90 sec. *Permanent equipment* (since January 4, 1960): Press-Ewing N, E, Z, T_0 = 30 sec, T_g = 90 sec.
San Francisco, Calif.	Discontinued operation of Sprengnether Z, T_0 = 2 sec, T_g = 2 sec, July 28 1959. Added Lehner and Griffith (moving-coil) Z, T_0 = 1.2 sec, T_g = 0.3 sec, Oct. 9, 1959.
Vineyard, Calif.	New station (February 3, 1959) 36°45.0′ N, 121°23.0′ W, elevation 328 m. Equipment: Wood-Anderson (torsion) N, E, T = 0.8 sec; Marion (moving-coil) Z, T_0 = 1.0 sec, T_g = 0.5 sec.
Yerington, Nev.	Discontinued Sprengnether seismograph operation June 1957.
No Change: Ferndale, Fresno, Manzanita Lake, Mineral, Mount Hamilton, Palo Alto, and Shasta, Calif.; Reno, Nev.; and Corvallis, Oreg.	
JESUIT SEISMOLOGICAL ASSOCIATION	
Cape Girardeau, Mo.	New vault under construction, ready fall of 1960. 2 horizontal Sprengnether seismometers will be installed at that time.
Chicago (Loyola), Ill.	Sprengnether seismometers, N, E, T_0 = 7 sec, T_g = 7 sec.
Cleveland, Ohio	Short-period Benioff seismometer, Z
Florissant, Mo.	1 Sprengnether seismometer Z, T_0 = 30 sec, T_g = 90 sec. 2 Sprengnether seismometers, N, E.
Fordham, N. Y.	Several Willmore seismometers Z.

Stations	Remarks
Washington, D. C. (Georgetown)	Short-period Wilson-Lamison seismometer, Z, T_0 = 1 sec, T_g = 1.2 sec. Sprengnether seismometers, N, E, T_0 = 7 sec, T_g = 7 sec.
Little Rock, Ark.	Wilson-Lamison seismometer, Z, T_0 = 1 sec, T_g = 1.2 sec. Short-period Reeff seismometer, N.
Saint Louis, Mo.	Short-period Benioff seismometer, Z, T_0 = 1 sec, T_g = 1 sec.
No Change: Spring Hill, Ala.; San Francisco and Santa Clara, Calif.; Denver, Colo.; New Orleans, La.; Weston, Mass.; Buffalo, N. Y.; Cincinnati, Ohio; Spokane, Wash.; and Milwaukee, Wis.	
SEISMOLOGICAL LABORATORY	
Big Bear, Calif.	Station discontinued September 20, 1957.
Dalton, Calif.	Benioff strain, displacement transducer added. Benioff Z, T_0 = 1 sec, T_g = 0.2 sec, discontinued approximately Oct. 1959.
Hayfield, Calif.	Benioff Z, T_0 = 1 sec, T_g = 90 sec, T_g = 0.2 sec.
Isabella, Calif.	Benioff strain, displacement transducer and experimental instrumentation.
Mount Wilson, Calif.	Benioff moving-coil seismometer T_0 = 1.5 sec, T_g = 0.25 sec replaced by variable reluctance seismometer T_0 = 1.0 sec, T_g = 0.2 sec, Oct. 7, 1959.
Pasadena, Calif.	Press-Ewing N, E, Z, T_0 = 30 sec, T_g = 90 sec. Press-Ewing Z, T_0 = 80 sec, T_g = 90 sec. Gilman modification Press-Ewing, T_0 = 60, T_g = 480 and 110 from displacement transducer coupled through 50-sec TC and 200-sec TC network, respectively.
San Nicolas Island, Calif.	Benioff Z, T_0 = 1 sec, T_g = 90 sec and 0.2 sec. Wood-Anderson, E, T_0 = 0.8 sec.
No Change: Barrett, China Lake, El Centro, Fort Tejon, Haiwee, King Ranch, Palomar, Palos Verdes Riverside, Santa Barbara, Tinemaha, and Woody, Calif.	
All stations have 115 kc or 9277.5 kc time signal radios, Marine chronometers, tuning fork and quartz clocks. Most stations have battery standby for lamps and motors.	
COAST & GEODETIC SURVEY	
Boulder City, Nev.	Benioff Z, variable reluctance, operated from July 2, 1958 to Aug. 29, 1958
Bozeman, Mont.	McComb-Romberg horizontals replaced by Sprengnether N, E, February 1959, T_0 = 11 sec, T_g = 8 sec.
College, Alaska	Benioff Z, replaced by Wilson-Lamison Z, T_0 = 1.5 sec, T_g = 0.45 sec.
Eureka, Nev.	Benioff Z, variable reluctance, operated from July 7 to Aug. 28, 1958.
Guam, Mariana Islands (Magnetic Observatory)	HTL Z, T_0 = 0.5 sec, T_g = 0.53 sec; Wilson-Lamison Z, T_0 = 1 sec, T_g = 1.7 sec; Sprengnether, N, E, T_0 = 8.9 sec, T_g = 6.8 sec, 13°35′15″ N, 144°51′58″ E.
Guam, Mariana Islands (Navy)	Seismograph station discontinued Dec. 17, 1959.
Honolulu, T. H.	Columbia N, E, Z, T_0 = 15 sec, T_g = 75 sec.
Hungry Horse, Mont.	Benioff, N, E, Z replaced July 21, 1958 by: Benioff Z, variable reluctance, T_0 = 1.05 sec, T_g = 0.5 sec, T_g = 92 sec, Wilson-Lamison N, E, T_0 = 3.5 sec, T_g = 4 sec.
Kipapa, Hawaii	Benioff Z, moving-coil, T_0 = 1.0 sec, T_g = 0.2 sec, and Wilson-Lamison Z, T_0 = 0.5 sec, T_g = 0.5 sec operated from April 4, 1957 to Nov. 1, 1957 HTL Z, T_0 = 0.5 sec, T_g = 0.2 sec, operated April 4, 1957 to April 15, 1958. Benioff Z, variable reluctance, film and paper, operated from April 15, 1958 replacing HTL Z. Film discontinued Feb. 4, 1959.
Koror, West Caroline Islands	Discontinued operation December 31, 1958.
Lincoln, Nebr.	McComb-Romberg E replaced by Sprengnether N, E April 1959, N, E, T_0 = 4 sec, T_g = 6.5 sec.
Thule, Greenland	Sprengnether N, E, T_0 = 6.0 sec, T_g = 7.5 sec, operated from Aug. 22, 1957 to Jan. 26, 1959. Wilson-Lamison, Z, T_0 = 1.3 sec, T_g = 1.6 sec.
Truk, East Caroline Islands.	Discontinued operation Dec. 31, 1958.
Tucson, Ariz. (Telemeter)	Benioff Z, T_0 = 1.1 sec, T_g = 0.5 sec.
No Change: College (Outpost) and Sitka, Alaska; Byrd and South Pole, Antarctica; Tucson, Ariz.; Ukiah, Calif.; Balboa Heights, Canal Zone; Chicago, Ill.; Butte, Mont.; Philadelphia, Pa.; San Juan, Puerto Rico; Columbia, S. C.; Rapid City, South Dakota; Salt Lake City, Utah; and Washington, D. C.	

Stations	Remarks
INDEPENDENT STATIONS	
Boulder, Colo.	Discontinued operation 1959.
Duluth, Minn.	Discontinued operation 1959.
Mayfield, Wash.	Benioff short-period and long period Z installed Sep. 1959.
Palisades, N. Y.	Columbia N, E, Z, T_0 = 30 sec, T_s = 100 sec, operating with flat response curve; Columbia N, E, Z, T_0 = 30 sec, T_s = 100 sec, operating with peaked response curve in surface wave period range and notch filters to eliminate microseisms; Columbia Z, T_0 = 30 sec, T_s = 100 sec, without notch filter. Strain meter operates at Ogdensburg, N. J.

No Change: Fayetteville, Ark.; San Diego, Calif.; Hawaiian Volcano Observatory, Hawaii; Terre Haute, Ind.; Lawrence, Kans.; Harvard and Williamstown, Mass.; Ann Arbor, Mich.; Buffalo-L, N. Y.; City College of New York, N. Y.; Chapel Hill, N. C.; Pittsburg, Pa.; State College, Pa.; Waynesburg, Pa.; Dallas and Lubbock, Texas; Bellingham and Seattle, Wash.; Morgantown, W. Va.; Madison, Wis.; and Laramie, Wyo.

Magnitude and Energy of Earthquakes

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Three magnitude scales are in use in the United States: The magnitude M_L of the original Richter scale, based on the maximum trace amplitude recorded in near-by shocks by a standard Wood-Anderson torsion seismograph; the magnitude M, based on the largest ground amplitudes of surface waves having periods of about 20 sec [*Gutenberg and Richter*, 1956, p. 3]; the unified magnitude m, based on the ratio of the ground amplitudes to their periods in body waves [*Gutenberg and Richter*, 1956, pp. 5–9]. The relationship between the three magnitudes, especially between M_L and the others, is not well established. *Gutenberg* [1956a] and *Gutenberg and Richter* [1956] have found that approximately

$$m = 1.7 + 0.8M_L - 0.1M_L^2,\ M - m = 0.37 \quad (M - 6.76), \text{ and } m = 0.63M + 2.5 \qquad (1)$$

and that the order of magnitude of the energy E of an earthquake is given by

$$\log E = 5.8 + 2.4m \text{ ergs} \qquad (2)$$

For the San Francisco earthquake of 1906, approximately $m = 7\frac{3}{4}$, $M = 8\frac{1}{4}$ for which (2) gives $E = 2 \times 10^{25}$ ergs.

Knopoff [1958] has studied theoretically the stress distribution and the relative motion throughout a medium with uniform shear modulus which is subjected to a shear stress. On simplified assumptions he finds for the depth to the bottom of the crack in the San Francisco earthquake of 1906 only 3.2 km, and an energy difference of the shear fields before and after faulting of 4×10^{25} ergs.

Byerly and DeNoyer [1958] have calculated the energy in earthquakes from geodetic observations. On simplified assumptions, they find 0.9×10^{25} ergs for the energy of the San Francisco earthquake, 9.6×10^{25} ergs for the Imperial Valley shock of 1940 (to be compared with 8×10^{25} ergs from m), and (1 to $1\frac{1}{2}$) $\times$ 10^{25} ergs for the Fairview Peak, Nevada, shock of 1954 (4×10^{25} ergs from m).

† Deceased, Jan. 25, 1960.

DeNoyer [1958, 1959] has estimated the energy in body and surface waves in a given earthquake and has applied his theoretical results to a number of shocks. In most instances, his calculated energies are roughly 1/30 of those found from (2). He also finds that the ratio of the energy in surface waves to that in body waves varies. Shocks which produce surface breaks usually have relatively large energy in the surface waves. The energy in shear waves is frequently greater than that in longitudinal waves.

Tocher [1958] has found empirically that the energy E of an earthquake with fault breakage (length L, maximum displacement D at the fault) is approximately $3.4 \times 10^{27}\ LD$.

Gutenberg [1957a] has observed that in the body waves of earthquakes certain frequencies prevail. In a given earthquake the ratio a/T of ground amplitudes a to the period T which is used in the calculation of m decreases, if at an epicentral distance of over 2000 km the wave period T exceeds about 10 sec in P, 12 sec in PP and 20 sec in S. This has to be considered in calculations of the magnitude m. Another correction in magnitude determinations is necessary for the effect of the ground [*Gutenberg*, 1957b], especially, if short-period waves are used. At stations on water saturated ground the amplitudes of short waves may be as much as ten times too large, compared with those on crystalline rock under otherwise similar conditions.

If magnitude determinations are applied to records of nuclear explosions [*Carder* and *Cloud*, 1959; *Romney*, 1959], the results agree with (2) within the rather large limits of errors involved (roughly one unit in log E). Romney finds that on the average

$$M = 3.65 + \log Y \qquad (3)$$

where Y is the yield in kilotons. Romney observed that the magnitudes M_L and m agree approximately on the basis of records of nuclear explosions.

A list of the values of m and M for the major earthquakes of 1957, prepared by Gutenberg, has been reproduced in the Bulletin of the Seismological Society of America, vol. 49, p. 422, 1959.

On the assumption that (2) is correct, the following energies (in 10^{24} ergs) have been released (h = focal depth)

Year	$h \leq 60$ km	$60 < h \leq 300$ km	$h > 300$ km	All
1956	1.2	0.46	0.29	1.9
1957	6.4	0.91	0.27	7.6
Average 1908/55	6.0	1.55	0.29	7.9

For shallow shocks during the years 1896–1955, the corresponding data have been given by *Gutenberg* [1956b, p. 613]. The corresponding values for intermediate and deep shocks have not been listed, but given in graphical form [*Gutenberg*, 1956a, p. 11].

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Seismic Wave Propagation

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The major emphasis has been on theoretical studies of fundamental aspects of wave propagation and combined theoretical and experimental studies pointed at unraveling the complicated nature of seismograms to glean more information about the propagating medium and the source.

Studies on diffraction, scattering, and attenuation were completed, thus laying a foundation for elastic wave propagation analogous to that which exists for electromagnetic waves. The Cagniard-Pekeris method was extended and applied to surface waves and interface waves for buried sources. The dual nature of surface waves as normal mode oscillations and superposed multiple reflections was further explored. Higher modes of crustal surface were identified on seismograms and shown to be sensitive to the structure of the upper crust and sedimentary layers.

The complex modes of surface waves (leaking modes) were studied theoretically and the dispersion and attenuation of these waves were computed for several special cases.

Long surface waves received much attention. Experimental studies based on many samples of mantle Rayleigh waves with periods from 40–600 sec were made. Whereas previously these analyses were rare, requiring earthquakes of very large magnitude, the new long-period seismographs now provide almost daily records of mantle Rayleigh waves. Comparison of theoretical and experimental dispersion curves of mantle Rayleigh waves demonstrates that the Gutenberg upper-mantle low-velocity zone occurs everywhere although somewhat shallower under the oceans than the continents.

Phase velocity of surface waves has been measured experimentally using tripartite arrays of stations. A method for determining phase velocity from the data of one station was developed and successfully applied. These measurements are useful in revealing crustal structure and in synthesizing seismograms.

Theoretical and numerical studies of surface-wave dispersion in heterogeneous media were carried out using high-speed electronic computers. These numerical computing advances removed a major obstacle to the use of surface waves for determining the fine structure of the mantle.

Using measured amplitudes of P waves from large explosions, the shadow zone at distances of about 1000 km caused by the low velocity zone in the upper mantle was verified and better detailed.

Free oscillations of the Earth received much attention following earlier experimental indications that they may be observable. Calculation of periods and excitation functions for spheroidal and torsional modes were carried out using several different numerical methods on high-speed computers. As an adjunct to these computations, the effect of the Earth's curvature on the dispersion of long-period surface waves was evaluated.

The use of waves other than P to deduce the nature of the source was investigated. Several methods of operating on surface waves to reveal the source function were developed and applied to ultrasonic model studies as well as studies of large explosions and earthquakes. The procedures were shown to be feasible and there is much optimism that a new powerful tool is now available to derive the tectonic setting of earthquakes. A by-product of these studies is a technique of deriving theoretical seismograms of surface waves which bear a remarkable resemblance to observed seismograms.

In model seismology a method for fabricating two-dimensional models with continuously variable velocities and densities was developed and applied.

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Microseismic Research

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Microseismic work conducted by United States investigators during the triennium 1957–1960 may be classified under three categories which are summarized as follows:

Review of old data—In April 1959, the U. S. Coast and Geodetic Survey published a 196-page report entitled *The Microseismic Program of the U. S. Navy, a Terminal Report* by Dean S. Carder and Robert A. Eppley. In the report are reproduced complete microseismic ampli-

tude data from stations operated by the U. S. Navy in the Atlantic-Caribbean hurricane area and in the southwest Pacific typhoon area during the 12-year period 1944–1955. Storm tracks, amplitude-distance-intensity graphs from selected hurricanes and typhoons and microseismic versus wave data are also reproduced. It was concluded that hurricanes, typhoons, and other storms at sea are responsible for the generation of storm microseisms, and that such microseisms indicate the presence of a disturbance at sea which may be a tropical storm —if in season. However there is often a lag by as much as 36 hours between the closest passage of the storm and the maximum microseismic amplitudes. Such a lag would not be expected if the microseisms were generated in the vicinity of the storm and may be explained in terms of the travel time of the swells from the storm to the continental boundary or coast near the station. The reflection of these swells or opposing swells generated by other means would create the proper condition for the wave interference theory of microseismic generation.

The 'wave-interference' theory of microseismic generation formulated by Longuet-Higgins has in recent years gained considerable support. According to this theory, wave trains of the same frequency, meeting each other in opposite directions, will cause fluctuating pressures on the ocean bottom which are twice the frequency of the wave trains. It further states that these second order pressure fluctuations are not attenuated with depth.

A comparison of microseismic amplitude and period at certain stations with data from wave gages situated near the stations has shown a high degree of correlation between microseisms and swell. Although small microseisms may be generated directly from the storm center, the study concludes that the major microseismic generating mechanism at coastal and island stations is associated with the interference of swells near the stations. The Navy experience of attempting to track tropical storms using tripartite stations was not satisfactory, and other attempts using relative amplitudes at several stations was partially satisfactory. Additional research using arrays more extensively than a tripartite array was recommended. It was found that about one tropical storm a year could be sensed by the microseismic technique as early as 24 hours prior to sensing by other techniques.

Collection and evaluation of raw data from IGY stations—In Antarctica, 5 stations are operated in whole or in part by United States scientific teams; the South Pole and Marie Byrd stations by the Coast and Geodetic Survey; the Wilkes station by California Institute of Technology; and the Scott Base and Hallett jointly by New Zealand and the United States. Available records have been only partially analyzed. Since the intermediate-period seismograph at the South Pole was inoperative during the first half of the IGY, that station is of little value in microseismic work. No short-period microseisms were recorded by the Benioff vertical seismograph indicating that such microseisms will not penetrate this far inland. One year's records from the Byrd station have been evaluated. From this one-year sample it appears that the months of greatest microseismic activity are March and September. The quietest months are October, November, and December. There is no indication that the ice pack has a damping effect on intermediate period microseisms. When open water is exposed during January and February only moderate activity is evident. Dominant microseismic periods range from 6 to 8 sec although 4.5-sec periods have been observed. There is as yet no definite tie-in to weather conditions, because of lack of isolation of storms about the continent. One apparently isolated storm in the Ross sea is under study at the time of writing. Correlation of microseismic data between the stations is also under way, but no report is as yet available.

In the arctic, data from Thule are available but have not as yet been evaluated.

In the Pacific Islands, IGY stations from which data are available are located on Guam, Koror, and Truk. Supporting data from the Philippine and Japanese stations are also available. Nine tropical storms within reach of the three IGY stations have been studied. In general the results confirm findings contained in the U. S. Navy report, summarized above, but there is also evidence that some microseismic peaks are concurrent with times of greatest storm intensity when the storm is nearly a thousand miles distant. Whether or not local conditions may be the cause of these microseismic peaks has not been determined.

In connection with the United States IGY microseismic effort relative to routine stations on the continent and elsewhere, four stations are known to have participated in a measurement of microseisms at 6-hour intervals. They are San Juan, P. R.; Morgantown, W. Va.; Sitka, Alaska; and Honolulu. The readings over a period of several years are available but they have not as yet been evaluated. Somewhat over a decade ago a large mass of data from world stations was collected with little or no correlation between the data from the different continents. More recent United States effort has been the study of case histories, but there has been very little of that since 1957.

Independent research—Four instances of independent research by United States investigators since 1957 have been found in the literature.

Paul Pomeroy (Lamont Geological Observatory) gave a paper at the AGU meeting May 4–6, 1959 entitled *Background and Storm Microseisms in the Period Range 11–22 sec.* Detection of these microseisms is possible because of the filter system which removes the shorter periods from the records. The amplitudes are from 0.01 to 0.1 those of the 6 to 8 microseisms. They are believed caused by gravity wave action near the shore.

Cecil A. Nanny (U. S. Naval Research Laboratory) in *Nature*, March 22, 1958, reported that there is a close correlation between microseismic frequencies and amplitudes and earthquakes.

J. E. Dinger (U. S. Naval Research Laboratory) in *Earthquake Notes*, vol. 27, no. 2–3, reported a lag in microseismic amplitudes observed on Barbados which would allow travel time of the swell to be reflected from the South American coast and return to Barbados.

Ross F. Heinrich (St. Louis University) in *Earthquake Notes*, vol. 27, nos. 2–3, using new instrumentation in a tripartite net found that 0.3- and 0.6-sec microseisms were moving waves but came to no conclusion as to their origin.

Geodetic Measurements Related to Crustal Movements and Particularly Earthquakes

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The Coast and Geodetic Survey has continued its program for re-triangulating and releveling over geodetic monuments in areas of seismic activity. After the San Francisco earthquake of March 22, 1957, a triangulation party was instructed to reobserve the network of points in the San Francisco Bay area and eastward to the higher mountain stations. This network had been observed in 1951 as a part of the long-range program for Earth movement studies.

A comparison of the two surveys showed movement of points in the same direction as had been determined previously. The magnitude of the movement, 2 to 3 feet, was greater than had been anticipated from data based on earlier surveys. There was no indication of any large displacement along the San Andreas Fault.

Also in 1957, about 2000 mi of releveling was undertaken in California over a net of lines covering a region from the vicinity of Los Banos south to Wheeler Ridge. Although this releveling is of particular interest to those studying subsidence in the San Joaquin Valley, it also covers areas of earthquake investigation. Anchors were secured in bedrock in the Sierra Nevada and Coast Ranges and also a tie was

made to tidal observations at San Luis Obispo Bay.

In 1958 a traverse network in the vicinity of Palmdale, California, was reobserved. A comparison of the new measurements with the old did not disclose any significant movement.

In 1959 a triangulation and traverse network in the vicinity of Taft and Maricopa, California, was reobserved. There are many oil wells, pipelines and refineries in this region. Engineers responsible for the maintenance of the pipelines had reported evidence of horizontal displacement. At the end of the year, the computation and adjustment of these resurveys had not been completed so that there are no results to report at this time.

The classical method for the analysis of these measurements is to make a comparison of coordinates or elevations based upon two or more surveys made ten years or more apart, or made before and after an earthquake. The differences in position or elevation are then interpreted as movements in the Earth's crust.

The accumulation of accidental errors in surveying plus the uncertainties due to the selection of stable points may lead to erroneous interpretations. In an effort to arrive at more definitive results, a different type of analysis for the triangulation has been developed. In areas such as those adjacent to the San Andreas Fault we can assume that the Earth's crust is being deformed and that small rectangular areas near the fault line are being deformed into parallelograms by major forces acting within the Earth's crust. In a conventional network of triangulation the horizontal directions or observations of lines radiating from a single point can be used to determine the amount and rate of this deformation. It is assumed that the direction of the force is parallel to the fault line and that the angle for which the magnitude and rate of deformation are to be computed is from a direction perpendicular to the fault. If some of the lines in a triangulation network actually cross the fault line an additional unknown may be inserted in the equations. This unknown represents the slippage or displacement which might have occurred along the fault line.

This numerical type of analysis is particularly effective in regions where there has been no earthquake between the dates of observation. When an earthquake occurs there are generally large displacements on each side of the movement of the fault and usually in opposite directions. This newer type of analysis has been applied to networks along the San Andreas Fault.

In a network near Hollister, California, the results from surveys made at a 20-year interval indicated an annual angular rate of deformation of 0.″1 and an annual slippage of 10 mm. In another network near Cholame, California, the angular rate of deformation was about the same but the indicated slippage was only 2 mm per year.

It is hoped that funds will be available to use the same mathematical analysis on all previously observed networks as well as those planned for reobservation in future years.

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Current Developments in Seismological Research

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Progress in seismological research during the IGY period may be considered under the following heads: (1) Epicentral studies on the distribution of earthquakes; (2) Body-wave studies of the internal structure of the Earth; (3) Rayleigh-wave and Love-wave studies of the crust and mantle; (4) Crustal strain studies; (5) Microseism studies; (6) Explosion-blast studies of the crust; (7) Explosion-blast studies of surficial geology.

The principal investigators were the U. S. Coast and Geodetic Survey (Items 1, 2, and 4), the Seismological Laboratory of the California Institute of Technology (Items 1, 2, 3, and 4), the Lamont Geological Observatory of Columbia University (Items 2, 3, 6, and 7), the Department of Terrestrial Magnetism of the Carnegie Institution of Washington (Items 6 and 7), the Woods Hole Oceanographic Institution (Items 6 and 7), the Scripps Institute of Oceanography of the University of California (Items 6 and 7), the Department of Geology of the University of Wisconsin (Items 6 and 7), and Princeton University (Items 6 and 7).

Areas of study—To aid in the epicentral program as well as in the study of body waves, surface, waves, and microseisms several new seismic observatories were established by the United States Coast and Geodetic Survey. These were located on oceanic islands, in Greenland, and in Antarctica. Most of these stations are being continued and will form a valuable permanent addition to the world network of seismic recording stations. Nineteen special long-period seismographs were installed by the Lamont Observatory at locations distributed so as to form a world network. Two strain seismometer installations were made by the California Institute of Technology for the study of the rate of strain accumulation in the crust. One is located in California and the other in the Andes of South America.

The explosion program of seismic measurements can be divided into marine and continental measurements. The marine program of the Scripps Institute of Oceanography was mostly in the South Pacific area and between the Mariana Islands and South America. Most of these measurements delineated both the surficial geology of the ocean floor and crustal structure. The Lamont Geological Observatory operated in the South Atlantic area, in the Indian Ocean, the Caribbean Sea, Red Sea, and Mediterranean Sea. Most of these measurements were limited to a study of the surficial geology of the ocean floor and the nature of the underlying crust rather than the determination of the total crustal thickness. The Woods Hole Oceanographic Institution worked jointly with the Lamont Geological Observatory on the Indian Ocean, Red Sea, and Mediterranean Sea measurements. The Lamont group also had the cooperation of the Argentine Navy on the measurements along the Argentine Coast and adjoining south Atlantic area. Off Africa the South African Navy participated in the program.

Seismic measurements of crustal structure and composition on the continents were made in Chile and Peru by the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, in Arkansas and the Great Lakes region of the United States and in Mexico by the University of Wisconsin. Working together the University of Wisconsin, the Carnegie Institution and Princeton University made two reversed seismic refraction studies of the crust in the Rocky Mountain and High Plains region. The University of Wisconsin also carried out seismic studies of the surficial geology in the Atlantic Coastal Plain region of Georgia and South Carolina.

In Antarctica teams composed of personnel from several universities (principally Wisconsin and Columbia) and the Air Force Cambridge Research Center carried out seismic measure-

ments of ice thickness along traverses based on the Little America, Byrd, Ellsworth Stations, and McMurdo bases. The program was supplemented during the IGC period with an air lifted operation to permit rapid reconnaissance in areas of difficult ground transport and at great distances from the base camps. This program was carried out by the University of Wisconsin.

Some significant results from seismic programs—From the dispersion of Rayleigh waves from distant earthquakes traversing the United States, *Ewing* and *Press* [1959] showed that the crust varies in thickness between 34 km and about 50 km and that the variations in crustal thickness correlate in general with the surface elevation and Bouguer gravity anomaly values. *Press* and *Dewart* [1959] from similar studies in Antarctica were able to show that the crust beneath eastern Antarctica is of continental thickness, but that in western Antarctica appears to be more like an island archipelago with a crust of intermediate thickness. From a study of the dispersion of long period Rayleigh waves *Dorman* and others [1960] verified that there is a velocity reversal in the upper part of the mantle beneath the crust.

The epicentral studies particularly as regards Antarctica were of interest in that despite the surface geologic evidence of major faulting and volcanism along the boundary of the Ross Sea, the area is not now characterized by seismic activity. Only one earthquake (a minor one) having an origin in Antarctica was detected during the entire IGY period by the Antarctic network of seismological observatories. In the United States, *Woollard* [1959] showed that although the epicenter distribution over the country could be correlated with the geologic tectonic pattern, there were many areas of geologic derangement that had been inactive throughout the historical record. Further, the distribution of areas of seismic activity over the past 25 years showed no correlation with the geologic age of the provinces involved, and that the focal depths of most earthquakes within the continental interior appear to originate at or near the base of the crust rather than at any fixed depth or at random depths.

The crustal seismic program at sea confirmed earlier measurements that the thickness of the crust in the oceanic basins averages only 5 to 6 km in thickness with only a thin surficial cover of sediments of the order of 1 km in thickness. Of particular interest, though, are the anomalous results noted by the Scripps Oceanographic Institution in the Pacific Ocean area. (1) In a deep water embayment in the Tuamata Island platform a normal ocean section was found although the surrounding platform is a shallow water area. (2) East of the Eastern Island Rise, the crustal layer appears to be only about 4 km thick and is layered with a basal member 2 km thick having a higher than normal velocity of 6.7 km/sec. (3) Beneath the Nasca Ridge beneath 2900 m of water the crust is about 15 km thick. (4) At four locations on the Eastern Island Rise no velocity value greater than 7.5 km/sec was obtained for the mantle. As this is an area where the heat flow appears to about five times normal presumably the mantle velocity is affected by the abnormal thermal conditions. Of particular interest are results obtained on profiles parallel to and along the axis of the Peruvian Trench off the coast of South America. The base of the crust showed a progressive deepening towards the continent from −11 km to −23 km with no local thickening of the crust beneath the trench.

A similar result was obtained by the Lamont Geological Observatory over the Bartlet Trough in the Caribbean Sea. In the Caribbean area it was also found that the crustal thickness could not be correlated with depth of water, that the crust had complex variations in internal structure and appeared to vary in character from that typical of oceanic areas to that associated with the continental areas.

The continental seismic measurements made in South America by the Carnegie Institution on the basis of second and third arrivals, indicate a very thick crust (over 65 km) beneath the high Andean plateau with values of the order of 45 km in the foothill area. These values taken in conjunction with the measurements across the Peruvian Trench indicate a smooth transition from the thin crust beneath the adjacent ocean floor to the thick crust beneath the Andean Mt. system.

On the North American program the significant result obtained from the University of Wisconsin measurements was that where the crust is characterized by positive isostatic grav-

ity anomalies it is apt to have both a high density and a greater thickness than would be deduced from either the surface elevation or the Bouguer gravity anomaly values. In Arkansas, for example, it was found the crust consists dominantly of material having a velocity of about 7 km/sec with an inferred density of about 3.0 gm/cc and a crustal thickness of 43 km where the Bouguer anomaly values are +10 mgal (+15 isostatic) and the surface elevation is less than 100 meters. Intermediate layering was observed on all profiles although in the Great Lakes area it appeared to be chiefly as a result of compression within the upper 2 to 5 km which caused an increase in velocity from about 5.5 km/sec to 6.1 km/sec (see *Steinhart*, and others [1958] and *Woollard* [1959]).

The program of seismic measurements in Antarctica for determining the thickness of the ice present showed a considerably greater thickness of ice to be present than was formerly realized. An average thickness of about 3000 meters appears to pertain to most of western Antarctica with values in excess of 5000 meters in some areas. As the surface elevation lies between 2000 and 5000 meters the rock floor beneath the ice over much of the area now lies well below sea level. In eastern Antarctica on the other hand the rock floor in general lies above sea level and in places rises over 2000 meters above sea level. If the ice were removed and the area rose to an equilibrium position it appears that much of western Antarctica would constitute an island archipelago (see *Bentley* and others [1960]).

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Advances in Seismic Exploration

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Introduction—Advances in techniques and new methods of seismic exploration for oil and minerals which have a dollar value are not published with the same alacrity as might be expected of similar advances in 'pure' science. This time lag has been minimized by a series of articles entitled *Geophysical Research and Progress in Exploration* published in *Geophysics* which report briefly on new developments approximately two years in advance of more definitive publication. Those articles and other papers cited in this summary reveal many significant advances during the period 1957–1960 including two new methods, five new techniques, and four aids to interpretation.

New methods—A new seismic method which employs frequency-modulated continuously-excited seismic waves was first reported in a

research and progress paper [*Dunlap* and *Johnson*, 1958]. A recent article [*Crawford* and others, 1960] describes the principles, the equipment, and gives examples of the results. The method uses correlation of the impressed and received signals as a means of unscrambling the complex received signals, and utilizes sophisticated procedures and instrumentation. Although it is still in the research and development stage, this new seismic method appears promising.

Continuous velocity logging in the bore-holes is a comparatively new method whereby the velocity in a well is measured continuously over a 6-foot interval [*Summers* and *Broding*, 1952; *Vogel*, 1952]. The method aided seismologists to improve their understanding of the seismic reflection process. Recently geologists have found this tool useful in correlating wells and production engineers have evaluated sand reservoirs from these data [*Hicks* and *Berry*, 1956; *Wyllie* and others, 1958]. *Pickett* [1960] applied the electric log as a means for correcting the acoustic log for the effects of shale contamination of producing sands. The increasing demand for accurate acoustic logs has encouraged the development of a two-receiver logger. This receiver records continuously a vertical refraction profile of the material adjacent to the bore-hole. The measurements are nearly independent of variations in the diameter of the bore-hole [*Kokesh* and *Blizard*, 1959].

New techniques—The dropping of a heavy weight as a means of generating seismic waves was described in a research and progress paper [*Dobrin* and *Dunlap*, 1957] and was evaluated in more recent papers [*Neitzel*, 1958; *Domenico*, 1958]. This technique records on magnetic tape the signals generated by individual weight drops and then combines the results from 15 to 100 spaced weight-drops to enhance the amplitude of the reflections while canceling some of the undesired waves. The technique is especially useful where drilling of shot-holes is either prohibitively expensive or impractical. The records obtained are usually of lower frequency than those obtained by conventional practice. The longer period reflections are sometimes a desirable by-product of the method although this advantage may be at the expense of precision.

Undesirable ghost reflections were identified by *Van Melle* and *Weatherburn* [1953]. They can be reduced by a field technique described by *Musgrave* and others, [1958] and by a data processing method which employs a linear filter [*Lindsey*, 1960].

The 'Marine sonoprobe' [*Dobrin and Dunlap*, 1957] is a technique of reflection mapping of very shallow under-water geologic markers whose source of energy is an electric spark. *Beckmann* and others [1959] describe similar techniques. A recent paper by *McDonal* and others [1959] describes a system using a 20-ft long detonation gun of sufficiently rapid fire so that from two to 16 recordings can be composited to increase the amplitude of the signals. Consistent data are obtained to a depth of 4000–5000 feet. All of the techniques were designed primarily as low-cost reconnaissance methods for exploration of water-covered areas. A procedure for reducing water reverberations in conventional marine reflection work is described by *Backus* [1959] wherein an inverse linear filtering operation removes the prime 'filtering' or singing effect of the water layer.

Multiple geophone and shot-point arrays continue to receive serious attention [*Savit* and others, 1958; *White*, 1958]. These and other techniques for record improvement in difficult areas are expensive and no one method is universally applicable. *Graebner* [1960] has described a testing process which indicates the proper palliatives for an area by fairly exhaustive tests in a minimum of time.

Dobrin and *Dunlap* [1957] remark on the rejuvenation of the refraction method. While not a new technique the new application is partly the result of improvements in instrumentation, especially better low-frequency response.

Aids to interpretation—The most spectacular advances in seismic exploration are in development of aids to the interpretation of seismograms. The use of magnetic recording [*Loper* and *Pittman*, 1954] permits playback of the recorded data with any desired filtering while corrections for computed weathering and for the variable moveout are made automatically.

Data can be displayed using the conventional galvanometer response [*Palmer*, 1957] or as variations in either the photographic density (variable density) or the width of a line (variable area). Instrumentation permits the recording of any desired number of adjacent seismic profiles on a single sheet of paper. Events previously obscure are more readily perceived

and the overall picture becomes apparent. Miniaturization of playback equipment has proceeded so rapidly that the entire process can now be handled [*Hall*, 1959] in a field office. Work is progressing in the development of compositing and stacking techniques which use a combination of the *Pieuchot* and *Richards* [1958] and of the rejuvenated *Rieber* [1936] methods. Conventionally recorded data can be transferred to magnetic tapes by use of a semi-automatic device whose trade name is 'Seisverter.'

Automation procedures which were reported by *White* and *Press* [1960] include the use of digital electronic computers for routine computations and automatic plotting of migrated depth points. These authors also report an analog-to-digital computer which will punch the times from magnetic tapes into cards for pre-selected reflection picks. An accuracy of one millisecond is claimed.

Multiple reflections have been recognized in their simpler forms for many years. Subsequent to the work in Germany of *Bortfeld* [1956], *Levin* and *Lynn* [1958] have offered direct experimental evidence of the existence of multiple reflections. *Berryman* and others [1958] and *Wuenschel* [1960] have investigated this problem theoretically and applied their results to the analysis of acoustic logs by means of analog and digital computers. Their results can forewarn the interpreter of problem areas, so that multiple reflections can be identified at least on a statistical basis. The problem of reducing their tendency to mask useful information has not been solved. Since multiple reflections are a function, however complex, of preceding events the solution may possibly be found in application of the *Wadsworth* and others [1953] and *Robinson* [1957] philosophy in combination with other properties of multiple reflections.

An attempt at the solution of the perplexing stratigraphic problem is described in a preliminary report by *Savit* [1960]. Energy is integrated over a short time and the average response of all record traces actuates a galvanometer. Evaluation of this technique is currently in progress.

Fundamental research is not within the scope of this summary but it should be mentioned that work is continuing on attenuation and dispersion studies [*McDonal* and others, 1958] and in the problems of scattering [*Knopoff*, 1959ab] and diffraction [*Knopoff* and *Gangi*, 1959].

Conclusion—The vigor of present day seismic exploration is readily apparent in this summary. The challenge today is not only to improve significantly on present methods, but to do so at a cost which is economically permissible in the precarious world oil situation.

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Gravity Tide Measurements

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During the International Geophysical Year two LaCoste-Romberg gravity-tide meters were employed to obtain observations at 13 stations distributed in the equatorial belt. Thirty to 45 days of observations were obtained at each station. The results, which will be discussed subsequently, are listed in Table 1.

The data—The gravity variations were continuously recorded graphically on a chart 10 inches wide to the approximate scale 0.6 mm = 1 microgal, 1 inch = 1 hr (except at the two African stations where 1 inch = ½ hr).

Reduction of data—Records were read at ½ hr intervals by an 'OSCAR' reader, which enables the readings to be automatically recorded on punched cards. Gaps in the record were supplied by the following method of interpolation, devised by I. Longman. Instrumental drift was first removed by the Pertsev method. Next a least-square fit to all the available readings in the record was made by the two parameter formula $g(t) = Ag_* + B(dg_*/dt)$. Here the function $g_*(t)$ represents Newtonian values at the observing station of tidal gravity on a rigid Earth. The above formula was found to fit the observations with surprising precision throughout long intervals, of duration 30 days. The maximum discrepancies between observed gravity and the formula were of the order 4 microgals.

After making the interpolations the Pertsev correction was removed, so that the original data only (with interpolations) were used in the subsequent analyses.

TABLE 1—*Summary of gravity-tide results for semi-diurnal lunar constituent M_2*

No. (1)	Station (2)	Coordinates Lat.	Coordinates Long.	Date (4)	Instrument no. (5)	$\delta = 1 + h - 3/2k$ (6)	Phase lag, κ (7)	k, (8)
200	Honolulu	21°18'N	157°49'W	Oct. 13, 1956 Nov. 23, 1956	2	1.191	+2.0°	0.365
201	Glendora	34 10.2N	117 48.6W	May 27, 1957 July 8, 1957	2	1.184	−3.8	0.352
202	Wake Isle	19 18 N	166 39 E	July 26, 1957 Sep. 4, 1957	2	1.174	+0.5	0.333
203	Manila	16 24.6N	120 34.8E	Sep. 18, 1957 Nov. 1, 1957	2	1.202	−2.6	0.386
204	Saigon	10 47 N	106 42 E	Nov. 22, 1957 Jan. 2, 1958	2	1.163	−0.5	0.312
205	New Delhi	28 38 N	77 11 E	Jan. 12, 1958 Feb. 15, 1958	2	1.154	−1.6	0.294
206	Bunia	1 32 N	30 11 E	Feb. 28, 1958 Apr. 5, 1958	2	1.183	−0.8	0.350
403	Bukavu	2 14.3S	28 48.0E	Mar. 5, 1958 Apr. 7, 1958	4	1.160	+1.8	0.306
404	Winsford	53 12.5N	2 31.1W	Jun. 30, 1958 Aug. 14, 1958	4	1.216	+4.1	0.413
	Mean					1.181	−0.1	0.346

The records were then analyzed on the IBM 709 computer by a method devised by MacDonald and Ness. This method resembles the power-spectrum method of Tukey and others in that the record is uniformly analyzed at regular frequency intervals without prejudice through pre-selection of specific tidal periods. In the scanning of the record a 'window' of optimum type was developed with the object of minimizing the contribution of diffraction sidebands.

The tabulated results refer to the major semi-diurnal constituent M_2. To enable the static values of h and k to be determined from the observed gravitational quantity $\delta = 1 + h - 3/2\,k$, the value $k/h = 0.48$ for the static case) has been adopted. This value is close to the value 0.4848 [*Slichter*, 1960] deduced for the equatorial bulge on the basis of observations of artificial satellites, and is also near the middle of the range 0.458 to 0.507 computed by *Alterman* and others [1959] and by *Molodenski* [1953] for various elastic earth models.

In the paper by Alterman and others cited above, the relations between the static values of k and h and those at the 12-hour excitation period are developed. Using these relations and allowing for the effects of the Earth's rotation, one finds for the static value k, $= 1.912\ (\delta_D - 1)$ where δ_D is the observed (dynamic) value of the gravitational quantity listed in column (6) of Table 1. The corresponding values of k, are listed in column (8). The average 0.346, is close to the value 0.34 obtained by *Markowitz* [1959] from analysis of the lunar tidal terms in the variation of the speed of rotation of the Earth, and slightly larger than the value 0.31 obtained by *Munk* and *MacDonald* [1960] from the period of the Chandlerian wobble.

It is interesting to note that the mean phase lag κ is only 0.1°, which is well below the significance level of the observations.

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Flow, Fracture, and Strength of Rocks in the Laboratory

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Introduction—The design of a physical experiment is usually based on the theory to be critically tested. However, there are few even phenomenological theories to guide the laboratory work on rock deformation. Because the current state of knowledge of the flow, fracture, and strength of rocks is largely empirical, and because the research is costly and time-consuming, the judicious choice of experiment is difficult, but appears to have been fortunate. Of the four natural environmental factors which significantly influence the mechanical properties of deeply buried crustal materials—confining pressure, pore pressure, temperature, and time —only the first had been adequately investigated prior to 1957. Our understanding of the effects of pore pressure and of temperature (except on the carbonates) has come almost entirely from studies made during this past triennium. Although relatively little study was devoted to the time factor, experimenters have been keenly aware of its importance, and several workers have renewed the research after a lapse of nearly 20 years since the pioneering investigations of D. Griggs.

Apparatus—The rapid progress of experimental research has depended upon the design and fabrication of new highly specialized equipment. *Griggs* and others, [1960a], and *Handin* and *Hager* [1958] have extended the temperature range of triaxial compression tests to 500°C at 5 kilobars by using externally heated tool-steel pressure vessels with low-friction loading pistons. The former workers have raised the limit to 800°C by constructing an internally heated test chamber. They have also built a shearing apparatus capable of normal pressures of 20 kilobars at 800°C to obtain very large shear strains.

Handin [1958], *Robinson* [1959], and *Heard* [1960] have devised triaxial compression tests in which pore pressure can be applied independently. In Handin's apparatus the void volume of a porous specimen can be measured throughout the deformation.

To achieve greater flexibility of loading, *Handin* and others [1960] have built apparatus in which specimens can be twisted while under triaxial compression, and D. Griggs and H. Heard (personal communication, December 1959) are planning to load cubic specimens, perhaps to 100 kilobars, with three sets of mutually perpendicular, separately actuated hydraulic rams.

Constant-stress creep testing of rock salt is being carried out by P. Le Comte (personal communication, October 1958) at moderate pressures and temperatures with the view of relating the secondary creep strain rate to the rate of self-diffusion in halite.

Handin has begun an investigation of the creep of sedimentary rocks and expects to relate the creep strain rates to the magnitudes of the constant differential stress (to 1 kilobar), of the confining pressure (to 3 kilobars), and of the temperature (to 400°C).

In their triaxial compression tests at 5 kilobars, 500°C, *Griggs* and others [1960a] noted that the yield stress of Yule marble was reduced about 20% as the strain rate was lowered from 10^{-4} to 10^{-5} per second. H. Heard (personal communication, December 1959) has perfected a device for constant strain-rate creep tests down to 10^{-4} per second. He and Handlin hope to correlate their results from both types of experiments on at least one rock.

Effects of temperature—*Griggs* and *Handin* [1960] believe that there are only three fundamental macroscopic processes involved in rock deformation. *Extension fracturing* occurs in very brittle materials. *Faulting* occurs in transitional materials with or without loss of cohesion and release of stored elastic strain energy. Ductile materials deform by *uniform flow*. From the large body of experimental data (Table 1), they conclude that all materials will pass from

TABLE 1—*Summary of high-temperature experiments*

Material	Confining pressure	Temperature	Ultimate strength	Principal deformation mechanisms
	kb	°C	kb	
Anhydrite[1]	1–2	25–300	3–6	Faulting, 25°–150°; unidentified gliding, 300°
Dolomite[1] rock	1–2	25–300	4–6	Faulting, 25°–300°; intracrystalline gliding, 300°
Halite[1]	1–2	25–300	0.1–0.6	Intracrystalline translation; gliding {110}, 25°–300°
Limestone[1]	1–2	25–300	3–6	Faulting, 25°–300°; {1011} translation, {0112} twinning, 150°–300°
Sandstone[1]	1–2	25–300	2–4	Faulting, cataclasis; shear fracture at low pressure
Shale[1]	1–2	25–300	2–4	Faulting; unidentified gliding, 150°–300°
Siltstone[1]	1–2	25–300	1–2	Faulting, cataclasis; shear fracture at low pressure
Slate[1]	1–2	25–300	2–4	Shear fracture
Plagioclase[2]	5	400	5–10	Albite, pericline twinning
Dolomite crystals[3]	5	25–500	2–7	{0001} translation, 25°–400°; {0221} twinning, 400°–500°
Basalt[4]	5	500–800	2–10	Faulting, 500°; unidentified uniform flow, 800°
Calcite crystals[4]	5	500–800	0.3–1	{1011}, {0221} translation; {0112} twinning; {0001} translation, 800°?
Dolomite rock[4]	5	500–800	4–10	Faulting, {0221} twinning
Granite[4]	5	500–800	4–12	Faulting, cataclasis; bending of micas
Yule marble[4]	5	500–800	0.5–2	Uniform flow by {1011} translation, {0112} twinning; recrystallization
Quartz crystals[4]	5	500–800	20–40	Shear fracture; flow less than 1 %
Quartzite[4]	5	500	17	Shear fracture, cataclasis
Peridotite[4]	5	500–800	8–11	Faulting, cataclasis
Pyroxenite[4]	5	500–800	6–9	Faulting, cataclasis; {001} twinning, {100} translation in diopside
Solenhofen limestone[5]	0–8	25–700	1–7	From low to high pressure, temperature: shear fracture, faulting, uniform flow by intracrystalline gliding

[1] *Handin* and *Hager*, 1958.
[2] *Borg* and others, 1960.
[3] *Higgs* and *Handin*, 1959.
[4] *Griggs* and others, 1960a.
[5] *Heard*, 1960.

the brittle to the ductile state if the temperature or pressure or both are raised sufficiently. Some substances, notably quartz, have remained nearly intractable, but the ductilities of others are enormously enhanced. For example, ordinarily brittle limestone can be deformed more than 1000% at 5 kilobars confining pressure and 600° to 800°C.

Heating lowers the yield stress of all geologic materials tested with the single exception of dolomite crystals. The ultimate strength is also reduced unless the greater ductility permits more work hardening to occur prior to rupture. More usually heating tends to eliminate work hardening, and the high-temperature stress-strain curve is typically nearly horizontal. The temperature effect is large on rocks which deform principally by intracrystalline gliding (uniform flow) such as limestone and rock salt. The effect is relatively small on sandstone and igneous rocks which deform by faulting and accompanying cataclasis.

Effects of pore pressure—Triaxial compression experiments with independently controlled pore water pressures have been made by *Handin* [1958] on dolomite, limestone, sandstone, shale, and siltstone at pressures of 0–2 kilobars and temperatures of 25°—300°C, by *Robinson* [1959] on limestone, sandstone, and shale at 0-1 kilobar and room temperature, and by *Heard* [1960] on Solenhofen limestone at 0–2 kilobars and 25°–150°C. Ultimate strength and ductility depend upon effective confining pressure, the difference between external confining pressure and internal pore pressure, when the interstitial fluid is chemically inert, permeability is sufficient to insure pervasion of water and uniform distribution of interstitial pressure, and the configuration of void space is such that the pore pressure is transmitted fully throughout the solid phase. These conditions are satisfied by the porous limestones, sandstones, and shales. An explanation of the pore-pressure effect on the basis of Coulomb friction is consistent with the data on these rocks. High pore (low effective) pressure reduces friction and the rocks are weak and brittle.

The concept of effective stresses cannot, however, be validly applied to the deformation of the dense dolomite and Solenhofen limestone.

Cunningham and *Eenink* [1959] have conducted microbit rotary drilling tests on permeable rocks. The pore (formation) pressure, confining (overburden) pressure, and drilling fluid pressure were separately variable. The drilling rate of Berea sandstone is markedly reduced as the pressure difference across the bottom of the bore hole is increased because of (1) ineffective chip removal and (2) augmented rock strength. The latter effect is consistent with the triaxial compression test data of *Handin* [1959] on the same rock.

Effects of time—Kendall [1958] has made constant-load (compression) creep tests of about 30 hours duration on Solenhofen limestone and halite crystals at room temperature and under confining pressures up to 1 kilobar. His data satisfy the empirical relation

$$\epsilon = a + b \log t + ct^y$$

where ϵ = conventional strain (shortening), t = time, and a, b, c, y are empirical constants. The first term represents instantaneous elastic deformation, the second primary (transient) creep, and the third secondary (pseudoviscous or steady-state) flow. For limestone $y > 1$; for halite $y < 1$. The secondary flow is non-Newtonian since the term c decreases and the exponent y increases with increasing differential stress.

Constant-stress creep tests of a few minutes duration have been conducted by *Robertson* [1960] on limestones at room temperature and under confining pressures up to 4 kilobars. He observed only primary (transient) creep, described by the second term in the equation above. An increase of confining pressure on Solenhofen limestone from 1 to 2 kilobars causes a 100-fold reduction of strain rate per unit stress difference.

Brown and others [1959] have studied the flow of salt in hollow cylinders subjected to external pressure at elevated temperatures.

Applications to structural petrology—Laboratory work has provided specimens deformed under known conditions, enabling the structural petrologists to relate the microscopic deformation mechanisms to the deforming stresses. Dynamic interpretations can now be made from petrofabric studies of intracrystalline gliding in calcite, diopside, dolomite, and feldspar, and from kink banding in micas (Table 1); as well as of grain fracturing in quartz aggregates [*Borg* and others, 1960]. The experimental work has verified that the symmetry of the fabric of a strained crystalline aggregate is the same as that of the strain of the aggregate in bulk. It reflects the symmetry of deformation composed of the symmetries of the system of applied forces and of the initial rock fabric. Statistically, each grain, even in a heterogeneous rock, reacts as though it were subjected to the same stresses as the rock as a whole.

Dry syntectonic recrystallization has been achieved in highly deformed calcite marble [*Griggs* and others, 1960a]. The recrystallized grains are strongly oriented with their optic axes parallel to the maximum principal (compressive) stress. Annealing recrystallization of previously cold-worked calcite marble tends to de-orient the fabric [*Griggs* and others, 1960b]. The experimental fabrics strongly resemble those of some natural marbles.

Maxwell [1960] has produced large compactions and good cementations of water-saturated sands. The process seems to be largely grain

fracturing and rehealing, which may be important in nature. However, the extensive quartz recrystallization so evident in many natural sandstones has not been duplicated in the laboratory.

Future work—Experimenters firmly believe that their research on rock deformation has already contributed much to the understanding of many geological and geophysical problems, but must admit that the effectiveness of the work has suffered from the lack of theory. For example, the laboratory values of the strength of materials under conditions simulating the pressure and temperature of the Earth's crust must exceed reasonable estimates of the strength of rocks in nature by a factor of five at least. In the absence of theory we dare not extrapolate the experimental data even of creep tests to geologic time.

While he hopefully awaits the development of adequate theory, the experimenter can think of many problems that empirical results can resolve at least qualitatively. The large natural deformations of quartz remain an enigma. Artificial schistosity and slaty cleavage are unknown. The flow mechanism of shale is not well understood. Analytical studies of faulting and folding are often unrewarding because there are few, if any, proper rheological models for crustal materials.

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Isostatic Compensation, and Origin of Continents and Mountains

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During the past three years, the controversy between the two major schools of thought in tectonophysics was heightened by several exciting new developments. These two schools may be characterized as follows:

1. Those who believe the outer mantle is strong; that the departures from isostatic compensation serve as a measure of this strength; and that convection or other large-scale motion of the mantle is impossible.

2. Those who believe that the outer mantle is weak; that isostatic compensation is nearly perfect; that the observed gravity anomalies reflect transient density distributions brought about by dynamic effects in the mobile mantle; that convection or other large scale mobility of the mantle is the rule rather than the exception.

The 'immobile mantle' school has drawn much comfort from major new developments in the last three years. The first of these is *Clark's* [1956, 1957ab] discovery that radiative heat transfer in probable minerals of the mantle is substantial, and may greatly exceed ordinary conduction in parts of the outer mantle. The consequences of this on the thermal history of the Earth have been explored by *MacDonald* [1959]. While it is not clear that radiative heat transfer in the mantle is so large as to preclude convection, it is clear that this is an important new factor which must be taken into consideration in any attempt to view the Earth as a heat-engine. The uncertainties of the theory of radiative transfer are large, so that it is most important that conductivity be measured at high temperatures and pressures.

Another development of great significance is the new evidence of phase equilibria and the hypothesis that the Mohorovicic discontinuity is a phase change (basalt-eclogite) rather than a compositional change (basalt-peridotite). The determination of the jadeite stability field by *Robertson* and others [1957] provided the first concrete evidence that common crustal minerals undergo polymorphic transitions at about the pressure and temperature of the Moho. Kennedy, Boyd, and others have added much more data of similar import.

If the Moho is simply a phase change, then it will be deep in regions of high heat flow, and shallow in regions of low heat flow. Formation of a continent or mountain range would require no compression or other tectonic force, but only a high heat flow, plus regional isostatic compensation.

Hubbert and *Rubey's* [1959] theory of the origin of overthrust faults as a consequence of abnormal fluid pressure has important implications in this connection. This theory suggests that many features which have in the past been thought to indicate large tectonic compressions may be only superficial gravity, sliding down slopes of small inclination. Thus proponents of the phase-change Moho may argue that all aspects of continent and ocean formation, mountain-building, and epeirogenesis arise simply from variations in regional heat flow [for example, *Kennedy*, 1959]. Erosion, which would destroy an old-fashioned continent in a few per cent of the Earth's history, now merely moves material from continent to ocean without affecting the relative height of the two, since these are maintained by the heat flow and isostasy.

The 'mobile earth' school, claiming that all is not this simple, point to other new developments to support their contentions. *Von Herzen's* [1959] new heat flow measurements which nearly double the total reliable heat flow data in the world, raise problems for the phase-change Moho. Von Herzen, in extending Maxwell's heat flow measurements in the Pacific, finds broads regions of abnormal heat flow. The whole of the Albatross Plateau has a heat flow several times normal. Other large regions have a heat flow only a small fraction of normal. If the Moho were a phase boundary,

and the same under continents and oceans, it would be much deeper in regions of high heat flow, and shallower in regions of low heat flow, contrary to observations.

Von Herzen's heat-flow data show a regional pattern which he notes may reflect subcrustal convection—upwelling under the Albatross Plateau and sinking on either side. If the heat flow could be mapped over all the ocean area, this would provide a most effective test for hypotheses of tectonophysics.

Mason [1958] and *Vacquier* [1959] discovered large strike-slip displacements on the Murray, Mendocino, and Pioneer fracture zones by observing offsets of the prominent N-S magnetic anomalies. The correlation of magnetic profiles across the Pioneer Ridge fault [*Vacquier* 1959] constitutes better evidence for large strike-slip displacement (260 km) than has ever been obtained by other means. This displacement on the Pioneer Ridge fault is left-lateral, while the Murray fracture zone which is some 500 km to the south exhibits a right-lateral displacement of 160 km. Such mobility of the oceanic crust is greater than that imagined by any but the most ardent advocates of crustal and subcrustal motion. It is of utmost importance to determine the age of these faults.

From seismic and gravity measurements at sea, it has become increasingly apparent that much of the isostatic compensation must be below the Moho. There are three suggestions from seismic results as to how this occurs: (1) The common association of topographic highs with lower than normal subcrustal velocities. This suggests some isostatic compensation in a layer immediately below the 'crust.' (2) The preferential attenuation of short-period shear waves on certain oceanic paths [*Ewing* and *Press*, 1956] which suggests sub-Moho regional compensation by 'pockets of magma.' (3) The work of Dorman, Landisman, Sato, and Ewing on dispersion of surface waves confirms Gutenberg's low-velocity layer and suggests that it is higher under the oceans than under the continents. Differences between continents and oceans extend to several hundred km.

Satellite data have provided more accurate data on the first few spherical harmonic terms in the figure of the Earth than ever before [*O'Keefe* and others, 1959]. The departures from a figure in hydrostatic equilibrium must mean either a finite strength at depth, or density differences maintained dynamically, as by convection.

If progress continues as fast in the future as it has in the last triennium, there is a reasonable prospect that some of the major riddles of the Earth's interior may yield to combined field, laboratory, and theoretical attack.

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Tectonic Theories

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A well-know difficulty with the classical theory of isostacy is that the total thickness of sediments that may be deposited in a basin is determined entirely by the depth of the basin at the start of the process. Because of this, the deposition of large thicknesses of shallow-water sediments in geosynclines cannot be explained on the basis of the classical theory of isostacy. The results of a number of experimental studies on the stability of minerals at high pressures and temperatures [*Robertson* and others, 1957; *Boyd* and *England*, 1959; *Birch* and *LeComte*, 1960; and *Griggs* and *Kennedy*, 1956] suggest a mechanism by which shallow-water sediments can be deposited in great thicknesses in geosynclines. The experimental studies establish that many of the common minerals found at the surface of the Earth undergo transitions from a low-density to a high-density form at pressure-temperature conditions expected near the crust-mantle boundary. If the Mohoravicic discontinuity at the base of the crust is a phase transition then any change of the thermal and mechanical conditions in the crust will shift the position of the density discontinuity and there will be an accompanying motion of the surface of sedimentation.

MacDonald and *Ness* [1960] have carried out a numerical study of deposition of sediments on a model crust. The crust-mantle boundary is taken to be a phase transition. The equilibrium depth is fixed by the initial thermal state. Sediments are deposited on the upper surface of the crust. The increase in pressure caused by the loading of the sediments results initially in the conversion of low-density crustal material to the mantle phase of higher density. As a result of this conversion the phase boundary moves upward while the surface on which sedimentation takes place moves downward because of the density contrast between the crust and the mantle. The conversion of the low-density high-entropy phases to high-density low-entropy phases is accompanied by the generation of heat at the phase boundary. The generated heat will locally raise the temperatures and tend to displace the phase boundary downward in opposition to the effect of mechanical loading at the surface of sedimentation. Because of the low thermal conductivity of the sediments, the temperature at any fixed depth below the surface will be increased. The higher final equilibrium temperature in the crust results in a depth to the discontinuity greater than the initial depth. The greater depth to the discontinuity implies a thick crust and an elevation of the sediments above sea level. MacDonald and Ness find that the thickness of shallow crater sediments that may be deposited depends only on the amount of low-density crust that can be converted to the light density phase. The time scale for the process of sedimentation and uplift is on the order of 10^8 years.

A further mechanism for producing vertical uplifts has been suggested by *Hess* [1954, pp. 391–408]. A large density change is associated with the serpentinization of peridotite. Serpentinization of mantle material could result in the uplift of limited areas.

Wilson and Scheidegger have recently presented reviews of their thermal contraction theory of mountain building [*Jacobs* and others, 1959; *Scheidegger*, 1958]. A further advance in the thermal contraction theory has been the realization that phase transitions within the deep mantle raise the effective thermal expansion of the mantle and therefore increase the contraction that might result during the cooling of the Earth [*Birch*, 1952].

The thermal convection theories of mountain building continue to receive attention. However, no new quantitative analyses have been presented. *Billings* [1960] presents a comprehensive review of the current status of tectonic theories.

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Application of Electronic Computers to Seismological Problems

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In recent years electronic computing machines have been used as research tools in many of the physical sciences. Otherwise intractable theoretical problems and arduous and time-consuming procedures in experimental and observational problems have been overcome with the aid of fast computers. Seismology is one of the fields that has benefitted from the availability and use of computers.

In theoretical seismology we seek to construct seismograms that correspond to exactly specified conditions about source, receiver, and Earth structure. Only some of the very simple problems in theoretical seismology have been solved exactly. The derived expressions are complicated and a computer must be used to obtain the theoretical seismograms. This is also true for many of the approximate solutions.

In observational seismology, we attempt to extract data from seismograms for comparison with theoretical results and to aid in the construction of realistic Earth models. Recent developments in communication theory suggest that the interpretation of seismic observations can be greatly facilitated by numerical filtering procedures [*Blackman* and *Tukey*, 1959; *Cerrillo*, 1955]. A large amount of computation must be done to apply these procedures and to evaluate the theoretical solutions that have been obtained.

In this paper recent developments in theoretical and observational seismology that have been achieved with the aid of electronic computers are reported.

Garvin [1956] and *Gilbert* [1956] have obtained the exact solution to *Lamb's* [1904] problem in closed form by using a technique developed by *Cagniard* [1939]. *De Hoop* [1958] has modified and clarified this technique. Seismograms have been computed for a Poisson ratio of ¼. *Strick* [1958] and *Roever* and others [1959] have solved the problem of wave propagation in the vicinity of a fluid-solid interface and have computed several seismograms. *Gilbert* and *Knopoff* [1960] have computed numerous seismograms for Lamb's problem. As a part of their study of interface waves, *Ginzbarg* and *Strick* [1958] have computed Stoneley-wave velocities for a solid-solid interface.

Dorman [1959ab] has computed a large number of dispersion curves for plane layered media. He used a formulation developed by *Haskell* [1953] and based on the work of *Thomson* [1950]. Dorman's theoretical dispersion curves have been used in investigations of

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crustal structure by *Dorman* and *Oliver* [1958]; *Dorman* and others [1959a]; *Oliver* and others [1959ab].

The extension of Dorman's results to plane layered media having gradients in the physical properties of the layers has been made by *Landisman* and others [1959]. *Tolstoy* and *May* [1959] have computed dispersion curves for continuously stratified fluid media.

Further extension of dispersion analysis to a medium with arbitrary variation of elastic parameters and density has been made by *Satô* [1959]. His method consists of integrating the differential equations of motion on a computer. Only those solutions that converge and satisfy the boundary conditions are accepted. From the correct solutions phase-velocity dispersion curves can be constructed.

Phinney [1959] has computed several dispersion curves for high-order modes in a layered fluid. The higher modes can be used as an aid in picking late refraction arrivals.

Sherwood [1958] considered the problem of dispersion in an elastic slab and computed the trajectories of the mode generating poles in the complex-wave number plane. His work is a beginning of a better understanding of the role leaky modes.

For very-long-period surface waves the effect of the Earth's curvature becomes important. In addition the perturbation of the Earth's gravitational gradient is an important factor in the dispersion of long-period Rayleigh waves, but not Love waves. *Takeuchi* and others [1959] have extended theoretical dispersion curves for Rayleigh waves to 400 sec. Comparison of theoretical results with observations indicate the presence of a low-velocity zone in the mantle. *Gilbert* and *MacDonald* [1960] have extended theoretical dispersion curves for Love waves to 40 min by computing the free oscillations of the Earth in the toroidal (SH) modes. Their results are being expanded to include the spheroidal (P-SV) modes from which dispersion curves for Rayleigh waves can be computed for periods up to about one hour.

Inverse filtering or phase correction techniques have been employed by *Aki* [1959]. From dispersion analysis he constructs frequency functions that correspond to the dispersion properties in several areas. The reciprocals of these frequency functions are the inverse filters. Seismograms read at different stations for the same earthquake are corrected by inverse filtering to a common epicentral distance. Comparison of the corrected seismograms by cross-correlation methods yields information about the directivity of the earthquake source. The time history of the source can be studied by comparing the actual seismograms with synthesized impulse response. *Backus* [1959] has also used inverse filtering procedures to help remove multiple reflections in offshore seismic prospecting.

McDonal and others [1958] have computed Fourier transforms of recordings taken in the Pierre shale in an attempt to determine the attenuation properties of the shale. Their results indicate that the Q of the material is very nearly independent of frequency, a result that seems to hold for many solids [*Knopoff* and *MacDonald*, 1958]. *Satô* [1958] also used Fourier transform methods to compute attenuation in the upper mantle based on his study of G waves. By computing the relative phase of the G wave on successive paths around the Earth, Satô determined the dispersion curve of the G wave. From the dispersion curve he found the distribution of shear velocity in the upper mantle using *Takahashi's* [1955] solution to the inverse problem. The papers by *Satô* [1958] and *Aki* [1959] are good examples of how to use analytical methods and computational techniques to extract information from seismograms.

Recent improvements in long-period instruments have led to a revived interest in the free oscillations of the Earth. *Gilbert* and *MacDonald* [1959, 1960] have computed the free periods of toroidal (SH) oscillations for two Earth models. The surface displacement amplitudes have been computed for three kinds of point-stress sources at four source depths. Hopefully, comparison of observed free oscillations with the theoretical calculations could lead to a better Earth model. *Benioff* and others [1959] computed power spectra for tidal gravimeter and extensometer recordings relatively free of seismic disturbances. They conclude that if free oscillations are present the displacement at the surface is less than 0.005 cm. Their results suggest that the association of free oscillations with earthquakes is probably valid.

In summary we can say that the increase in

our knowledge of seismic processes and Earth structure has been achieved largely because we have been able to handle many problems with the aid of computers; problems that otherwise would have been very difficult or intractable. The successful blending of the results of theoretical investigations in elastodynamics, communication theory, and methods of computational analysis should lead to further increases in our knowledge and understanding in seismology.

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Earth's Crust below the Oceans and in Continents

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Oceanic areas—The Earth's crust beneath the oceans was studied by a variety of geophysical methods including those involving seismic reflection and refraction phenomena, seismic surface-wave dispersion, gravity, magnetism, and heat flow. The seismic-refraction technique provided the most extensive and detailed data, but valuable supplementary information was obtained from the other measurements. Seismic-refraction studies were carried out in previously unexplored parts of the North and South Atlantic, the North and South Pacific, and the Indian Oceans.

Beneath the deep oceans in regions well removed from continents, islands, or large-scale submarine topographic features, the main crustal rock layer is approximately 5 km in thickness and is characterized by a seismic velocity for compressional waves of about 6¾ km/sec. This layer is frequently overlain by a thin (about 1 km) layer of rock of compressional wave velocity of about 4½ km/sec. The upper layer of the column consists of unconsolidated sediments about ½ to 1 km in thickness and the velocities of compressional and shear waves, and probably therefore the density, vary measurably with depth. The mantle in such areas has a compressional velocity of slightly more than 8 km/sec. Beneath the areas of large-scale topography on the ocean floor, such as, for example, the Mid-Atlantic Ridge, the structure changes markedly. Sediments are generally thin but may occur locally in thick pockets. A layer of 2–4 km in thickness underlies the sediments and has compressional wave velocity of about 5½ km/sec which is markedly less than that of the normal crustal rock layer. This layer is underlain by rock with a compressional-wave velocity of about 7½ km/sec, clearly less than that typical of the upper portion of the Earth's mantle. The lower limit of this layer is as yet undefined. The transition zone between oceanic structure and continental structure is not yet well understood, but in some respects resembles that beneath the ridges.

Thermal gradient and conductivity measurements within the sediments indicate that the heat flow through the ocean floor is comparable to that through the continents. Anomalously high heat flow appears to be associated in general with the submarine ridges and anomalously low heat flow with the troughs.

In the Pacific, profiles of total intensity of the Earth's magnetic field on both sides of a fracture zone suggest large lateral displacements measured in hundreds of miles along the fracture zone.

In the southwest Pacific, gravity measurements were obtained with the Vening Meinesz pendulum apparatus aboard the British submarine H. M. S. *Telemachus*. Profiles across the Tonga-Kermadec Trench and Ridge revealed

free-air anomalies of about −200 mgal over the deepest part of the trench and of about +150 mgal over the Ridge. The anomalies over the Fiji Ridge to the west are close to zero.

Two gravity meters for use on surface ships have been developed. The Graf meter makes continuous gravity measurements over the Mid-Atlantic Ridge, through the Straits of Gibraltar, in the Mediterranean Sea, in the Blake-Bahama area, over the Middle America Trench, and over various sea mounts. The LaCoste-Romberg meter has been used for measurements in the Gulf of Mexico, in the Bahamas, and off the West Coast of the United States. Tests have also been made using the LaCoste-Romberg meter in airplanes.

It was reported that the mid-ocean ridge system, of which the Mid-Atlantic Ridge is a well-known feature, is in fact part of a world-encircling system, about 45,000 miles long. The rift which has been found to bisect the Mid-Atlantic Ridge has been found on practically all crossings of the ridge, and appears to be a continuous feature also. The hypothesis has been offered that the ridge and rift system can be attributed to convection currents in the mantle, and occurs in the zone of upwelling separating two convection cells.

Continental areas: The continental crust was studied primarily through the use of seismic refraction and reflection techniques, seismic surface-wave dispersion, gravity, and magnetism.

The seismic-refraction technique was used to study previously unexplored areas of the United States. Crustal structure is usually approximated by a maximum of three layers. The upper layer represents the sedimentary rocks and its properties are, of course, quite variable with location. The sediments lie on the upper crustal rock layer which has a compressional wave velocity of about 6 km/sec and which makes up a significant portion, sometimes apparently all, of the remainder of the crust. An intermediate layer with a velocity of about 7 km/sec is sometimes present at the base of the crust overlying the mantle which has a compressional wave velocity of just over 8 km/ sec. The depth to the mantle varies from about 30 to 50 km, apparently with the thicker crust occurring in regions of high mean elevation.

Surface-wave dispersion studies based on measurements of group velocity average the crustal structure over much longer paths in general than do the seismic-refraction studies, but the results of the two methods are in good agreement. Group-velocity data demand some manner of an increase of velocity with depth within the crust and clearly show the effect of the presence of low-velocity sedimentary rocks near the surface. Phase velocity measurements are more localized and apply to areas of the order of those studied by seismic-refraction technique. A study of the large number of phase-velocity measurements extending across the entire United States showed a close correlation with gravity values and, in general, direct dependence of crustal thickness on elevation.

Internal Constitution of the Earth; Physics of the Interior

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Even in geophysics, few topics are less suitable for a national report than is the internal constitution of the Earth. To decide which publications may be given a national label is frequently embarrassing. In the following bibliography it has seemed preferable to include titles which may legitimately appear in reports from other national committees rather than to

draw unduly exclusive distinctions. It is clear, however, that there has been much activity in the United States and some significant advances during the past three years. This topic is of course not independent of the work of other Associations of the Union, especially those of the Associations of Geodesy, Geomagnetism, and Oceanography, but it has not seemed necessary to duplicate the bibliographies of these Associations. What has become increasingly difficult to follow is the publication in many journals of the physical sciences of experimental and theoretical studies not especially directed toward geophysical problems but having implications for them. Such, for example, are the measurements of density at high pressures under shock conditions, and some of the determinations of melting curves to high pressures. Certain questions have now been transferred from the realm of speculation to that of experimental accuracy.

Developments in solid-state physics begin to play an increasingly important part in discussion of the Earth's interior. A particularly interesting area is that which deals with the related properties of radiative transfer, lattice thermal conduction and electrical conduction. The elusive problem of the internal temperature may be approaching solution through a combination of these studies with high-pressure melting point determinations, thermal calculations and geochemical considerations.

The following bibiography, by no means complete, may serve as an index of activity and possibly also as a guide to some of the less familiar but pertinent work which has appeared in the non-geophysical literature of (with a few exceptions) the last three years.

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METEOROLOGY AND ATMOSPHERIC PHYSICS

LEASON H. ADAMS, *Editor*

The General Circulation of the Atmosphere

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Interest in this subject has continued at a high level and only a selection of the research performed can be offered here.

With the increasing number of upper-air observations, in conjunction with IGY, subjects such as meridional exchange of mass, heat, momentum, etc., have become accessible to improved, though not yet perfect, determination. In addition, a new estimate of all components of the atmospheric heat balance has been made by *London* [1957]. This was possible mainly because of improved knowledge of the water vapor spectrum and because of better description of the atmospheric thermal structure.

Palmén [1958] strikingly brought out the important role of isolated vortices when he showed that two to four intense cyclones will suffice to furnish a hemisphere poleward of latitude 30° with the kinetic energy needed to maintain the general circulation against friction. Considering hemispheric data as a whole, various approaches by means of harmonic analysis have been made: for the troposphere by *Saltzman* [1957], *Saltzman* and *Peixoto* [1958], *Barrett* [1958], and *Benton* and *Kahn* [1957], and for the stratosphere by *Panofsky* [1958] and *Julian* [1959]. Individual harmonics, especially the lower wave numbers, have been studied concerning their role in meridional exchange and maintenance of the kinetic energy of the general circulation. Barrett also stressed the importance of the first harmonic in winter, which lends a spiral-like appearance to the high-tropospheric flow field.

Regarding moisture, *Benton* [1957] demonstrated seasonal convergence of latent heat over the continents in winter and divergence during summer. The water-vapor balance of various continents and the meridional flux of water vapor have been computed [*Starr* and *Peixoto*, 1958; *Starr*, *Peixoto*, and *Livodas*, 1958]. Even the ozone balance has been attacked by *Martin* [1958], who, in spite of scarcity of data, computed meridional and vertical ozone flux, and also rates of production and destruction of ozone, in different latitude belts for 1953.

At the climatic extremes, work on the stratospheric polar vortex of winter may be mentioned [*Wexler*, 1958; *Teweles*, 1958]. Of primary interest are the heat balance, the anomalous warming in late winter and the 'polar-night' jet stream. The subtropical jet stream of winter has been shown to be a powerful wind system [*Krishnamurti*, 1959] with mean core speed near 70 m sec; existence of a simple heat engine on the equatorward side of this current has been demonstrated for the winter 1955–56. *Palmén*, *Riehl*, and *Vuorela* [1958] found evidence of a mean meridional circulation in the tropics in winter with sufficient intensity to account for the production of the kinetic energy exported poleward across latitude 30°. In the equatorial zone the seasonal shift of the equatorial trough has been related quantitatively to heat export requirements [*Riehl* and *Malkus* 1958]; it is suggested that the whole vertical heat and mass transport in this zone takes place in narrow cumulonimbus 'hot towers' covering

only about 0.1 pct of the area of the tropics.

Theoretical research is being pursued among others by the group associated with J. Smagorinsky at the U. S. Weather Bureau who are developing general circulation prediction models, including heat sources and sinks, on large electronic computers. Using a two-layer model of the atmosphere, *Nielsen* [1959] computed the release of potential energy by large-scale vertical motions; his results are in agreement with those of *Pisharoty* [1955]. Model experiments by means of dishpans also continue to attract investigators. The theoretical contributions of *Kuo* [1957], and *Lorenz* [1957] may be mentioned. Experimentally, *Riehl* and *Fultz* [1958] showed that the general circulation can be represented as a simple heat engine in some experiments with steady wave motion with proper choice of a coordinate system. A monograph summarizing the experimental work of Fultz at the University of Chicago will be published by the American Meteorological Society in 1960.

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Upper Atmosphere Studies

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Introduction—As can be said about virtually every field of science, the field of upper atmosphere research has advanced very rapidly in the past three years. Moreover, there has been an apparent change in the *character* of the research. In part because of the impetus of the IGY, and in large measure because of the increased availability of better balloons, rockets, new radio and radar devices, etc., for probing the upper atmosphere, to say nothing of satellites, the research emphasis seems to have gradually changed from theoretical deductions, based on a modicum of facts, to a welter of facts, many of which cry for an adequate explanation by the theorists. Indeed, the aspect of the atmosphere has become ever so much more complicated since we have been allowed to view it properly, and it is likely that still more surprises lie in store for us.

Though all phases of upper-air research have been actively pursued, it may not be too presumptuous to point to two general areas where the advances since the IUGG meetings in 1957 have been particularly spectacular. These are, first, the filling in to some extent of the great gap in our knowledge about the 'forgotten region' between the ceiling of the balloon network and the ionosphere. The second general area where dramatic advances have been made is in describing the radiation environment of the Earth and its effects on the upper atmosphere. This environment includes, of course, both electromagnetic radiation from the Sun and an assortment of charged particles, and the complex changes which take place in the atmosphere cannot be understood without a knowledge of the changes in these inputs to it.

In attempting this brief and incomplete summary of upper-atmosphere research in the past three years, an arbitrary division will be made between the various regions in terms of the vehicles which have been used to explore them directly. This does an injustice to the various 'indirect' methods which have given valuable information, but some of the results of these methods will also be included here.

The upper air of balloons—Although the worldwide radiosonde balloon network has been in existence for many years, it has recently been possible to make synoptic analyses to levels of as high as 10 mb, or roughly 30 km, over the entire northern hemisphere and over Antarctica. This has given new insight into the flow patterns in the stratosphere, and it has become clear that they generally behave quite differently from the flow patterns to which meteorologists are accustomed. In the middle stratosphere the transition between seasons is a complex one involving a complete reversal of the general zonal flow from west in winter to east in summer. Motions of centers are usually many times slower, and the patterns more stable. [*Ohring*, 1958; *Wexler* and *Moreland*, 1958]. An important and very significant exception to this is the rapid 'breakdown' or 'explosive warming' in northern polar regions at 50 mb and above, which occurs at least once a year in the late winter months, sometimes several times. Several aspects of this phenomenon have received attention recently [*Godson* and *Lee*, 1958; *Craig* and *Hering*, 1959; *Scherhag*, 1958; *Palmer*, 1959].

Also within the height range of balloons is the body of the ozone layer, and the complex ebb and flow of ozone has been studied by means of two types of measuring devices, the chemical (Regener and Brewer) and the optical (Paetzold). The latter has recently been adapted for rockets. Moreover, during the IGY there was an expanded program to measure total ozone using Dobson instruments on the ground.

The upper air of rockets—The most extensive rocket sounding program during the IGY in terms of geographical coverage and numbers was that of the United States, involving nearly 200 rockets probing the atmosphere from the

Arctic to the Antarctic. The Soviet rocket program was also very active, and this period saw Great Britain, France, Australia, and Japan begin the use of sounding rockets. A preliminary review of all these programs (except the French rocket work) was held in Moscow in August 1958 [*Kellogg*, 1959; *World Data Center A*, 1958].

Just prior to the IGY a masterful summary of conditions in the upper stratosphere, mesosphere, and lower ionosphere was published by *Murgatroyd* [1957], and reference is made to this as a model against which to compare the recent results. As far as winds, temperatures, densities, and pressures are concerned, Murgatroyd's model holds up remarkably well except in polar regions in the lower ionosphere. The deviations even there are relatively minor. The curious reversal of the winds with altitude between 90 and 100 km at middle latitudes has been amply confirmed [*Elford*, 1959; *Manring* and others, 1959; *Agy*, 1958; *Harang* and *Pedersen*, 1957; *Harnischmacher*, 1958], and this is closely related to a very large seasonal change in the vicinity of the mesopause at 80 km, which is colder in summer than in winter [*Stroud* and others, 1959; *Jones* and others, 1958]. At various latitudes the picture has been filled in by a large number of rocket flights, such as those reported for low latitudes by *Smith* [1960] and Stroud (private communication), and at high latitudes by *Stroud* and others [1959], *Mikhnevich* and *Khvostikov* [1957], and *Shvidkovskii* [1959].

At still higher levels, above 100 km, the atmosphere over Ft. Churchill in the northern auroral zone tends to be consistently warmer than at middle latitudes over White Sands, N. Mex. [*Horowitz* and *LaGow*, 1958; *Jastrow*, 1959]. This is presumably caused by the influx of auroral particles. Moreover, at these higher elevations there is a very marked diurnal change as well as the seasonal one, and in the wind field, observed at middle and high latitudes by radio techniques, this shows up as a combined diurnal and semi-diurnal shifting [*Elford*, 1959; *Agy*, 1958; *Harang* and *Pedersen*, 1957; *Harnischmacher*, 1958], more or less as had been predicted from tidal theory and geomagnetic observations [*Maeda*, 1957; *Vestine*, 1954]. The detailed wind structure which has been observed is actually more complex than anything which can be described in a simple general circulation model, and the vertical wind shear in the lower ionosphere is often remarkably abrupt [*Manring* and others, 1959].

The composition in the ionosphere has been determined in a number of U. S. and Soviet rocket flights [*World Data Center A*, 1958; *Mikhnevich* and *Khvostikov*, 1957], and it appears that the level at which diffusion begins to dominate over turbulent mixing (the 'level of diffusive separation') is at about 90 km over White Sands, New Mexico, and at about 110 km over Ft. Churchill, a difference which has not been explained and which might be due to different measuring techniques. The distribution of positive ions in the ionosphere has been measured, and reveals among other things that the dominant ion at 100 km over Ft. Churchill is NO^+, while at 200 km it is O^+ [*Johnson*, *Meadows*, and *Holmes*, 1958]. The dominant negative ion detected on these flights turned out to be NO^-_2.

A great many measurements of electron density have now been made with rockets, and provide details of the structure of the ionosphere which do not show up in ground-based ionospheric recorder determinations. Noteworthy have been observations in an aurora [*Jackson* and *Seddon*, 1959] during a polar blackout over Ft. Churchill, in which the enhanced and irregular ionization in the D-region was observed [*Seddon* and *Jackson*, 1959; *Kane*, 1959], and the Soviet observations of electron density profiles to levels well above the F2 region maximum, showing that the decrease of electron density with height in the upper ionosphere is quite gradual, as had been predicted. This type of observation has since been made in the United States [*Berning*, 1959].

Another aspect of rocket research has been the use of magnetometers to determine the presence of electric current sheets in the E region, and such flights have been made successfully in both equatorial and northern regions [*Cahill*, 1959ab]. The equatorial electrojet turned out to be a double sheet, while the observed polar currents were roughly in accord with the predictions of the dynamo theory.

The upper air of satellites—Rocket observations of pressure or density become difficult above about 200 km, due to the very low pressures and long mean free paths involved, and

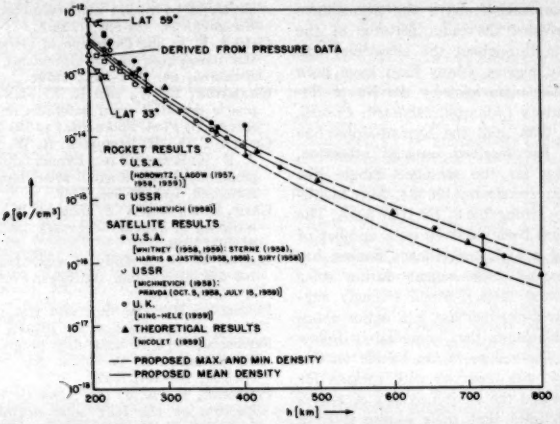

FIG. 1.—Densities derived from rocket and satellite observations, 200 km-800 km

the impossibility of outgassing a rocket during its short flight. However, it is just at this level and above that satellites have provided a considerable amount of good density data, these densities being deduced from observations of the effects of air drag on the orbit [*King-Hele*, 1959; *Schilling* and *Whitney*, 1959; *Schilling* and *Sterne*, 1959; *Harris* and *Jastrow*, 1959; *Kallmann*, 1959; *Siry*, 1959; *Paetzold*, 1959]. A recent summary of these density determinations was prepared by *Viezee* and *Kallmann* [1960], and is shown in Figure 1. The new densities are considerably higher above 200 km than had generally been anticipated before the satellite determinations.

A very intriguing outgrowth of these satellite densities has been the fact that there is a marked correlation between their fluctuations and solar activity. *Jacchia* [1959], *Priester* [1959], and *Paetzold* [1959] have studied this relationship in detail and conclude that a number of satellites, with perigees ranging from 200 to 650 km, have a change of drag which is directly related to both sunspot number and microwave emission from the Sun. Moreover, Jacchia found that 588$_1$ (Sputnik III rocket, with perigee at about 200 km) responded abruptly to two solar flares, after an interval of about a day-and-a-half. In fact, the drag increase occurred at almost the same time as the onset of the magnetic storms which followed these flares, suggesting that there was a large scale and sudden warming of the ionosphere accompanying these magnetic storms.

The Earth's radiation environment—The discovery of the Van Allen radiation belts, consisting of charged particles trapped in the Earth's magnetic field, has received so much attention elsewhere that it will not be treated further in this summary. Its implications to the understanding of the polar ionosphere have already been mentioned. The *sporadic* influx of energetic protons, usually accompanying magnetic storms, has received increasing attention in the past year [*Winckler* and others, 1959; *Anderson* and others, 1959; *Hultqvist* and *Ortner*, 1959], and it is likely that these surges of particles from the Sun account in large part for the phenomenon of the polar blackout, which is due to a widespread enhancement of ionization in the D region. In 1958 the upper atmosphere witnessed one of the most remarkable experiments in history, the *Argus* [1959] experiment, which introduced a band of artificial charged particles (electrons) whose presence was detectable by satellite for several weeks, and which caused aurorae at low latitudes initially.

Rocket observations above the atmosphere have now revealed the main features of the solar spectrum throughout the ultraviolet and the soft x-ray regions. Many lines have been identified in the ultraviolet by the Naval Research Laboratory [*Johnson, Malitson, Purcell,* and *Tousey,* 1958] and the Lyman-alpha line of hydrogen has received especial attention, since it is by far the strongest single line [*Chubb,* 1957; *Friedman,* 1959a]. Also identified has been a strong line of He II at 304A. The x-ray region has been observed on a number of occasions, and a highly significant finding has been its observed enhancement during solar flares [*Friedman,* 1959a], which strongly suggests that this x-ray increase is a major cause of the radio blackouts that immediately follow a solar flare. The eclipse in the Pacific on October 12, 1958, was observed with rockets for the first time, and the continued flux of x-rays at totality indicate that their source is to a large extent the solar corona rather than the photosphere or solar disk [*Friedman, Low,* and *Stonehocker,* 1959].

Finally, the flux of Lyman-alpha radiation at night, scattered from sunlight by hydrogen outside of the Earth's atmosphere, has been observed by Naval Research Laboratory rockets [*Friedman,* 1959b; *Kupperian* and others, 1959] and has given a partial explanation for the maintenance of the nocturnal E layer; and these measurements also provide a basis for estimating the density of hydrogen around the Earth (though it is being debated whether this should be interpreted as interplanetary hydrogen or a cloud of hydrogen in the Earth's vicinity, a sort of super upper atmosphere).

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Atmospheric Electricity

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Cloud-charging mechanisms and further details of the lightning discharge continued to be active research topics in this triennium and remain major problems under investigation. Considerable work on fair-weather soundings by aircraft and balloons to ascertain conductivity, field, and nuclei profiles has been brought to conclusion. Work on surface fair-weather measurements for synoptic, turbulence, or air pollution investigations was very limited. Measurement techniques for investigations of air electrical quantities are becoming sophisticated and are increasingly useful in contributing data required for solutions to problems in the above areas of research.

Review papers by *Reynolds* and others [1957] and by *Gunn* [1957] indicate divergent views on mechanisms required for production of the strong fields leading to lightning discharges. Observations by *Vonnegut* and others [1959]; *Fitzgerald* and *Byers* [1958]; *Phillips* and *Kinzer* [1958]; and by *Allee* and *Phillips* [1959] are compatible with the view that atmospheric ionization plays a significant role in the electrification of cloud and rain drops. However observations by *Brook* [1957], *Fitzgerald* and *Byers* [1958], *Shackford* [1958], and *Atlas* [1958] continue to emphasize the importance of the solid precipitation phase in lightning production.

The energy spectrum of the lightning discharge has been considered theoretically by *Hill* [1957]; measured by *Watt* and *Maxwell* [1957]; and extended to radar frequencies by *Atlas* [1958], *Rumi* [1957] has reported interesting echoes that appear to be reflections from discharges moving upwards from the upper troposphere to the lower ionosphere. *Sullivan* and *Wells* [1957] have constructed an efficient lightning stroke counter that has been calibrated by visual and radar observations.

Interpretations of surface electrostatic field and field change observations have been considered by *Smith* [1957, 1958] and by *Fitzgerald* [1957]. *Stergis* and others [1957] have measured fields and conductivity above thunderstorms, concluding that sufficient positive charge is transferred upward through the 70,000 to 90,000-ft level to confirm Wilson's hypothesis.

A series of clear-air aircraft soundings for electric field and conductivity profiles in the lower 6 km of the atmosphere have been reported by *Clark* [1957, 1958] and *Kraakevik* [1958a]. They conclude that the earth-ionosphere potential difference is 290 kV $\pm$ 10% and that the diurnal variation in potential is accurately described by the Carnegie average ocean-surface potential-gradient values. Conduction current above the exchange layer is found to be nearly constant with height, with a geographical variation from 1.1 to 4.1 $\times$ 10^{-13} A/m^2.

Aircraft measurements describing the variations of conductivity and charged nuclei content within and above the exchange layer as an air mass moves over the western Atlantic ocean were reported by *Sagalyn* [1958]. She finds that the pollution particles affecting the electrical properties of the exchange layer are primarily of land origin and are well-mixed through the exchange layer. Larger particles from the sea are not present in sufficient abundance to significantly affect the electrical properties above 500 ft. The concentration of charged particles of one sign is about 300 particles per ml. This corresponds to a total particle concentration of about 1000 per ml. The radius of maximum concentration is about 0.08 micron.

Conductivity measurements to above 26 km have been made by *Woessner* and others [1958] using balloon techniques and extended to 80 km by *Bourdeau* and others [1959] in a rocket experiment. The role of nuclei in altering the ratio of negative to positive conductivity in the lower 7 km is emphasized by the first authors. At altitudes above 50 km the latter authors found a reduction of conductivity which agreed

with that predicted from present estimates of radius and concentration of noctilucent cloud particles. The utility of airborne conductivity measurements for determining the distribution of radioactive debris in the atmosphere has been reported by *Clark* and *Kraakevik* [1959].

A major conference on Atmospheric Electricity was held at Portsmouth, N. H., in 1958 under sponsorship of the Aerosol Physics Laboratory of the Geophysics Research Directorate, Air Force Cambridge Research Center. Papers from this conference have been published in book form (*Smith*, 1958). Many interesting papers that could not be mentioned in this summary are contained in the Proceedings of this conference.

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Chemistry of the Atmosphere

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Work and progress in the chemistry of inactive atmospheric constitutents was concentrated primarily on the following problems: (1) The CO_2 cycle in the atmosphere and ocean. (2) The variation of isotopic constituents in water. (3) The distribution of rain water constituents over the United States. (4) The sulfur in the atmosphere.

The problem of the increase of the CO_2 in the atmosphere over the last 50 years by about 10% is of basic importance for meteorology and climatology. *Callendar* [1940], who detected this increase tried to explain it by the amount of CO_2 produced by the consumption of coal, oil, and other fuels since industry developed. This theory was seriously challenged by the consideration that the ocean will absorb considerable quantities of this additional CO_2 over the decades. If this was the case, the total amount of CO_2 released up to present times was not adequate to explain a 10% increase. These considerations could be confirmed quantitatively by extensive investigations of *Revelle* and *Suess* [1957], *Craig* [1957], *Arnold* and *Anderson* [1957], using carbon-14 as a tracer. They showed that the average residence time of CO_2 in the atmosphere is between 5 and 10 years. This is based on figures of carbon-14 content of organic material grown on land as opposed to that in the ocean and also on the decrease of the carbon-14 content in the atmosphere due to the release of the carbon-14-free CO_2 from fossil fuels. A residence time of 5 to 10 years, however, restricts the possible increase of the CO_2 content of the atmosphere to about 2% instead of 10% with most of the CO_2 entering the ocean. While these findings disprove Callendar's theory, the major problem as to why the CO_2 has increased by the observed amount remains still unsolved.

The various isotopic constituents of water, which result from the presence of oxygen-18, deuterium and tritium, provide a powerful tool in studying the cycle of water in the atmosphere and hydrosphere. The ratio of oxygen-18 to oxygen-16 in water varies in a systematic worldwide pattern by decreasing with the temperature at which the water condenses, that is with latitude and altitude. It also varies with the season being lower in the winter and this seasonal variation is useful in the study of many problems in glaciology. *Epstein* and *Sharp* [1959], made an extensive investigation of these variations and were able to determine the yearly rate of deposit in arctic and antarctic ice down to depth of several hundred meters. It is evident that these studies, when completed, will provide important information on climatic changes.

On the basis of a continent-wide rain water sampling network for chemical analysis, the large-scale distribution of various constituents could be studied. One of the dominant constituents in rain is sea salt which is present in the air as particles in the size range of 0.1 and 10μ, and which was intensely studied by *Woodcock* and *co-workers* [1957 and many earlier papers]. The maps of rain-water concentration of chloride and sodium [*Junge* and *Gustafson*, 1957], reflect very strikingly this origin by the rapid decrease inland from the coast line as was to be expected from earlier investigations in other areas. But this decrease stops at a certain distance from the coast and the concentrations remain surprisingly constant throughout the rest of the continent. It could be shown, that contrary to older concepts, the decrease in concentration along the coast is caused primarily by vertical mixing rather than wash-out by rain and that the sea-salt particles can penetrate far into the continent without too much loss.

It was further shown that terrestrial sources of sodium, potassium, and especially calcium, increase the rain-water concentration over land and reduce the ratio of chloride to these constituents considerably below the values found for sea water [*Junge* and *Werby*, 1958].

These studies indicated also the importance

of sulfur in the atmosphere. Considerable amounts of sulfur are always present in rain, even over the oceans [*Holzworth*, 1959]. It could be established that the main source of this sulfate in rain water is the oxidation product of the gaseous constituent SO_2 in the atmosphere [*Junge*, 1958]. Besides the photo-oxidation studied earlier by *Gerhard* [1953], the oxidation in solution is of importance in the atmosphere [*Junge* and *Ryan*, 1958]. A considerable fraction of the sulfate in rain originates from the release of SO_2 by industrial processes and this fraction is estimated to be about 30% on a global basis [*Junge* and *Werby*, 1958]. Sulfur is on a relative basis the atmospheric constituent most influenced by man.

Also, the nitrogen compounds were studied. *Robbins* and *others* [1959] could show that the most likely process of nitrate formation in the atmosphere is by reaction on sea-salt particles. This explains why nitrate is primarily found in coastal areas, as was earlier found in field investigations. The distribution of NH_4 and NO_3 in rain water over the U. S. was discussed by *Junge* [1958a].

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Research in Atmospheric Optics and Radiation

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Considerable progress and development have been made in this field in regard to the problems of light scattering in a planetary or earth atmosphere and in the general problems of infrared radiation, such as the computation of radiational fluxes, their measurement at the ground and the higher levels.

The analysis of the spectral distribution of the solar radiation and of its transmission through the atmosphere, measured in 1951, was

published recently by *Dunkelmann* and *Scolnik* [1959]. Their finding agrees in general, very well with the results of previous investigations.

The correctness of Chandrasekhar's exact solution of the radiative transfer in a pure molecular atmosphere was again demonstrated. The computation of the so-called global radiation, that is, the net fluxes of the sky and Sun radiation received on a horizontal surface, were extended by *Dave* and *Sekera* [1959] to include the correction because of the ozone absorption in the ultraviolet and visible part of the spectrum. The resulting values agree exactly with the values measured by Liljequist in Antarctica. Chandrasekhar's solution was used for the computation of the intensity polarization and other optical parameters of the light emerging from the top of a molecular atmosphere into the free space. These computations were performed on the IBM electronic computers (607 and 650) by *Coulson* [1959] for several values of the optical thickness, in different directions for various Sun's elevations. The effect of Lambert ground reflection was also included. The knowledge of the radiation emerging from the top of the molecular atmosphere is very important nowadays in the space technological application. At this occasion, the corresponding values for the skylight were recomputed and the values of the intensity and polarization parameters of the skylight and of the radiation emerging from the top of the atmosphere have been prepared for publication in the form of extensive tables. [*Coulson*, and others, in press]

Although extensive tables [*Penndorf*, 1957] of the coefficient in Mie series have been available for some time, very little progress has been made in the study of light scattering by aerosol particles in a turbid atmosphere. The major difficulty in this respect is the integration over the particle size distribution. In the forward direction the W.K.B. approximation of high frequency scattering, as derived by *Saxon* [1955], yields expression for the intensity components, which permit an easy integration with respect to the average size distribution of aerosol particles. This method was successfully used for the study of the Sun's aureole by *Deirmendjian* [1959a], leading to a good agreement of the theory and existing measurements. As suggested earlier [*Sekera*, 1952], another possibility of performing the integration over the size distribution of scatters in a turbid atmosphere, is to develop the intensity and the polarization parameters for large-particle scattering into Legendre series of the scattering angle. The corresponding parameters for a given size distribution of aerosol particles are given by the Legendre series, the coefficients of which are obtained by integration of the original coefficient in the Legendre series over the size distribution. This method was pursued by *Fraser* [1959]. Although the convergence of the resulting Legendre series is too slow to make this method practical for its application in the theory of radiative transfer in a turbid atmosphere, Fraser was able for the first time, to discuss the behavior of the different polarization parameters for various size distribution of aerosol particles.

While molecular scattering can be neglected in the programs of infrared radiation, the scattering by large haze particles in this spectral region may be quite considerable. This follows from the study of the role of water particles in the atmospheric transmission of infrared radiation by *Deirmendjian* [1959b]. Extension of this study to the far infrared region where the absorption by the water droplet has to be considered in addition to the scattering, will appear in the near future [*Deirmendjian*, 1960].

Theoretical studies of the radiational field in the optically dense media such as deep cloud layers, were studies by *Preisendorfer* and others [1958] for the purpose of designing a proper method for the determination of the volume absorption coefficient in such media. The optical measurements performed at higher altitudes above the ground deserve great attention, particularly in the measurements in high altitude aircraft and balloons. During the manned flight to 100,000 feet, the luminance of the horizon sky was measured, as well as the photometry of the sky at high altitude by *Duntley* and *Simons* [1958], and *Duntley* and others [1958]. The detailed results of these measurements are not yet available. Flights by unmanned balloons were used by *Stakutis* [1957] and *Toolin* [1957] for the measurements of the illumination of vertical surfaces, sky luminance, and the ground albedo.

Because of its important application in technology, the infrared radiation was studied by a large group of scientists. In the theory of spec-

tral band absorption, *Plass* [1958] discussed the different models and their application, particularly with respect to the spectral emissivity of CO_2. However, much greater development can be noticed in the experimental studies, in which the use has been made of the rapid technological advance in the construction of more suitable and powerful infrared detectors. For technical details of this development, the reader is referred to the proper chapter of the *Proceedings Institute of Radio Engineers*, September 1959, a special issue on *Infrared Physics and Technology*, (Section 4, S. Passman, editor). The infrared transmission in the open air over a path as long as ten miles has been measured by *Taylor* and *Yates* [1957]. These valuable measurements have been made across the Chesapeake Bay, almost at the sea level. The group from the Naval Ordnance Laboratory, White Oak, Maryland [*Templin and Talbert*, 1957] studied the atmospheric transmission from solar radiation from a mountain in Bolivia at an altitude of 17,000 feet. For the infrared measurements at much higher levels, up to 100,000 feet, the balloon-borne spectrometers were successfully used. The purpose of the measurements made by the group from Johns Hopkins University [*Strong* 1959] was to measure the upward radiation in order to separate the effect of terrestrial radiation in the measurement of infrared radiation from the other planets, as well as to determine the divergence of the radiation flux up to a very high level of the atmosphere. The purpose of the measurements made by the group of scientists from the University of Colorado at Denver [*Gates* and others, 1958; *Murcray* and others, 1960] was to determine from the solar spectra in the near-infrared, the amount of absorbing constituents at different altitudes, and to compare the atmospheric absorption with theoretical predictions of slant-path absorptions.

Attention also was paid to the problem of infrared transmission along slant path in the atmosphere. Because of the incompleteness of observational data from the upper level, the computation of such transmission has to be based on some mathematical model for the absorption bands. *Altschuler* [1957] corrected his previous calculations by using the new universal transmission functions developed by *King* [1957] which fit the data more closely. *Carpenter* [1958] recommends to use for such calculations the data obtained by laboratory measurements. He also introduced simple corrections to weather conditions.

Infrared measurements were also extended to the sky radiation from cloudless sky. Such measurements, performed on different locations by a group of members of the Aerial Reconnaissance Laboratory [*Bennett* and others, 1960], Wright Air Development Center, Dayton, Ohio, give an interesting insight into the problem of light scattering in the near infrared.

The need for the knowledge of the flux of the long-wave radiation emerging from the top of the atmosphere, for technological purposes, gave rise to the computation of this flux for different, selected meteorological conditions at various geographical locations. Using the available upper air measurements of the temperature and humidity, *Hales* and *Zdunkowski* [1959] computed the values of such flux, using the standard Elsasser's diagram.

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Arctic Meteorology

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Primary effort in arctic meteorology during the triennium 1957–1960 has been directed at observation and data tabulation. There has not yet been time for analyses of these data to appear in the literature in quantity or for the observation to exert a large impact on scientific thought in related areas. The United States established two drifting ice-pack observation stations in the Arctic Ocean as part of its International Geophysical Year program, and meteorological observations were maintained at these stations with interruptions occasioned by breakup of the ice floe on which one station was located, during most of the period, 1957–1960. The major objectives of the meteorological observations at these stations were the refinement of our understanding of the large-scale structure and behavior of the atmosphere and the calculation of mass and energy transfer across the ice-air interface [*Untersteiner* and *Badgley*, 1958]. Standard meteorological observations directed at the first of these objectives also were

made at many land stations in the Arctic and by reconnaissance aircraft flying at 700 and 500 mb from Fairbanks to within 300 miles of the North Pole and return. More specialized meteorological observations were made at a number of stations: rocket studies of the ionosphere at Ft. Churchill, Canada, glaciological observations on McCall Glacier, micrometeorology and radiation at Pt. Barrow, Alaska, auroral, ionospheric radio, cosmic ray, and geomagnetic observations at Thule, Greenland, for example.

Station A or Alpha was established on an ice floe at 81°N, 163°W in April 1957 and standard observations at the surface and in the upper atmosphere by radiosonde and rawinsonde as well as radiation and micrometeorological observations were made continuously until November 1958 when the station had to be abandoned due to breakup of the ice floe. An earlier break-up in May 1958 had forced a move to a new ice floe about one mile from the original site. The position of Alpha when finally evacuated was 86°N, 112°W.

The station established on Fletcher's Ice Island has been variously known as Station B, T-3, and Bravo. Standard surface- and upper-wind observations have been made as well as radiation and ionospheric observations. The station was located at about 83°N, 99°W in June 1959 and at 71.5°N, 145°W in January 1960.

The successor to Station A, known as Station Charlie or Alpha II was established in April 1959 at 74°N, 160°W and was abandoned due to break-up of the ice floe in January 1960 at 77°N, 167°W. Standard surface and upper-air observations were taken plus radiation and micrometeorological observations. All three of the drifting stations maintained extensive observational programs in a broad range of geophysical sciences; these are summarized elsewhere.

Arctic surface and upper-air observations have been used in the investigation of the characteristics of Arctic weather systems [*Keegan*, 1958; *Namias*, 1958; *Reed*, 1958ab, 1959]. Cyclones and anticyclones have been found to have much the same structure and behavior in the Arctic as in middle latitudes. No evidence for the existence of a quasi-permanent anticyclone near the pole has been found. Surface observations also have been applied to a study of the effect of topography on wind velocity; high winds at Barter Island appear to be explainable as resulting from deflection by the Brooks Mountain Range purely in the horizontal plane [*Dickey*, 1960].

Arctic upper-air observations also have been useful in the first extensive investigations of stratospheric and mesospheric circulation [*Teweles*, 1958; *Palmer*, 1959; *Craig* and *Hering*, 1959]. Existence of the cold polar vortex in winter in these layers has been established, and certain characteristic features have been identified. In particular, highly organized patterns of local stratospheric warming have been found to be characteristic of certain periods during each winter for which data are available. At the 50-mb pressure surface these local warmings may cover regions several thousand kilometers in horizontal extent and at the center may amount to 40°C or more in two weeks. Profound changes in circulation accompany these warmings. Although good progress has been made in description of this phenomenon, efforts at explanations have so far failed.

The data accumulated during the past three years in the Arctic region remain almost entirely unexploited. We may look forward in the next few years to enlightening analyses of these data, and we may hope that some of the analyses will contribute to basic understanding of atmospheric structure and behavior.

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Polar Atmosphere, Antarctic

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The unprecedented international scientific effort in the Antarctic during the International Geophysical Year (IGY), July 1957 to December 1958, and during the International Geophysical Cooperation (IGC) 1959, has provided basic data that are opening the way to significant advances in our knowledge of the Antarctic atmosphere. Preliminary results of investigations have enabled workers in this field to specify the large-scale features of the circulation from sea level to the lower stratosphere, the short-period and annual variations of the several meteorological elements, the radiation balance, some of the energy exchanges in the atmosphere-ocean-glacier system, and other heretofore undetermined atmospheric processes. Because of the previous lack of simultaneous data from all levels of the atmosphere at many stations over extended periods of time, most of the previous interpretations of Antarctic data in terms of large-scale factors in the atmospheric processes have to be reviewed in the light of current synoptic data. Much of the present effort has to do with describing the phenomena, and offering tentative explanations for them.

During the course of the IGY and IGC the character of the stratospheric circulation became evident. It differs markedly from the tropospheric circulation. In the stratosphere at the 50-mb level (about 18 to 20 km) the temperature rises from a monthly mean temperature of about −85°C in September to the maximum of about −30°C in November or December—as a 'sudden' warming that appears to work its way downward from higher levels. In the troposphere at the 500-mb level (about 5 km), for example, the lowest monthly mean temperature can occur in May or June as well as August, while the maximum occurs in December or January, and the difference between the two is only about 7°C. These reflect significant differences in circulation.

The stratospheric circulation in winter becomes progressively more zonal as the meridional temperature gradient grows stronger, mainly owing to cooling in the stratosphere. Stratospheric west winds, and the polar vortex tend to be symmetrical around the high plateau of East Antarctica; monthly mean values of 60 knots are not uncommon. The stratospheric cooling reduces the intensity of the tropopause and its inhibiting effect on vertical transports through it, although a second wintertime tropopause at 19 to 20 km may indicate the existence of a region of radiative equilibrium or subsidence. Wave patterns in the stratosphere are weakly defined, and the circulation undergoes little short-period variations. A sudden breakdown occurs with the return of the Sun, although the strong warming seems to be re-

lated more to subsidence and advection than to direct solar heating; easterly circulations then prevail for a short summer period.

In the middle troposphere a three- to five-wave pattern exists; it is strongly zonal but with enough amplitude and zonal translation to bring about appreciable short-period variations in wind and temperature all during the year. In general the surface isotherms tend to parallel the contour lines of height, although several significant anomalies are present. Another temperature feature, as yet unexplained, is a 48-hour cycle of surface temperature during winter at the South Pole.

The most marked of the temperature variations is the 'kernlose' winter phenomenon that is evident not only at the surface but up to heights of 5 to 7 km above sea level. It is likely that the rapid early-winter cooling and increased meridional temperature gradient contributes to greater cyclonic activity which, in turn, causes large temperature rises as air is brought in from the relatively warm oceans. Calculations show that heat transfer from ocean to atmosphere increases from summer to fall south of 60°S; the value of the transport (latent heat plus sensible heat) is about 300 ly/day. The late freezing of the oceans around the periphery of Antarctica effectively extends the continental area and is a significant factor in the late-winter minimum temperatures. At higher elevations the minimum surface temperatures tend to occur in late August or September; a minimum of −87.4°C has been recorded at the south geomagnetic pole.

A longer-term temperature trend of +2.6°C in 48 years has shown up in data from the northeastern section of the Ross Ice Shelf. No other records of comparable length from a homogeneous region are available in Antarctica.

Antarctica is a heat sink, requiring from 20 to 35 ly/day to achieve a radiative balance. The high surface albedo, averaging about 82%, is of considerable importance. The surface layers usually show strong temperature inversions, as much as 35°C in 850 meters on the high plateau, which are sometimes broken down due to the effects of cloudiness, mechanical turbulence, and large-scale circulations; the stratosphere generally cools in winter, but some reversals of this trend do take place. In trying to effect a heat balance, the atmosphere transports mass and heat, as well as water vapor into Antarctica; it almost succeeds in achieving a balance in the troposphere, but the air cooled over the continent flows outward again in the low levels. This is part of the easterly circulation in the lowest 1 to 2 km of the atmosphere; west winds increase in intensity upward and are strongest at about 65–70°S. In summer, however, the west winds are very much lighter, and easterly winds extend to about 5 km. The condensation of the small amounts of water vapor transported in the cold Antarctic atmosphere adds to the heat over the continent as well as to the snow deposited. From calculations of mass transport the snow deposit appears to be the equivalent of 7 cm of water per year. This figure agrees with estimates of the total annual outflow of ice-mass in East Antarctica, but is only about one-half to one-third of pit measurement of annual precipitation in West Antarctica. Precipitation in West Antarctica is higher than in East Antarctica for two reasons; (1) it is at lower elevations and thus allows easier passage for low-level cyclones, and (2) the center of atmospheric circulation lies over East Antarctica and the cyclonic storms tend to follow a zonal path that takes them across West Antarctica, with few incursions into the high plateau.

Ozone data tend to support the concept of a transport of mass into Antarctica in higher levels and outward in lower levels. Values of total ozone are highest in late winter, when no ozone is formed in the polar regions, and surface ozone values at Little America are also highest in that season. In addition, the highest values of surface ozone occur with winds from the southerly and westerly quadrants. Little America has a mean annual surface ozone value of about 45 micrograms/m³, which is about 25% higher than North American values.

Mass outflow over the winter season is greater than the inflow, as evidenced by the lower pressures in winter at the plateau surface. The strong cyclonic vortex in the stratosphere and the strong outflow of the cold air in the low levels are factors in the net outflow.

CO_2 values (about 311–313 ppm) seem to be uniform and vary little with time or with place in Antarctica. The lack of vegetation and exposed rock are probably the important factors.

The following Bibliography is representative of recent progress in the United States.

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Tropical Meteorology

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The renewed interest in tropical meteorology in the United States, engendered by the disastrous hurricanes of 1954 and 1955, has continued to flourish. Primary attention has centered on the data collection programs utilizing specially instrumented research aircraft, first provided through the Air Force Geophysical Research Directorate program and continued in 1956–1958 through the National Hurricane Research Project. These programs have provided essentially continuous flight-level observations of the atmospheric variables of most interest to the synoptic meteorologist and have, in a sense, added a new dimension in the investigations of the structure of weather and motion systems. It is interesting that extensive data of this type were first collected in the tropical and subtropical areas and that preparations for similar explorations of extratropical systems are only now in the planning stages. In spite of the glamor provided by the aircraft reconnaissance programs, many investigators have continued to work with more conventional aspects of the meteorology and climatology of the tropical areas. The references cited below have been selected in attempt to give a representa-

tive cross section of the principal types of research in tropical meteorology and climatology conducted during the past three years.

The utilization of mean-wind, temperature, and pressure data in the study of tropical cyclones, which has been quite popular in the past and which tended to extend over into the 1957–1960 period [*Krueger*, 1959, *Pfeffer*, 1958], has all but ceased and the significance of the models of tropical cyclones derived from the mean data is now being questioned [*Blumen and Laseur*, 1958; *Laseur*, 1959, *Malkus*, 1958]. The promise held out by the aircraft observation programs in the tropics has undoubtedly stimulated new theoretical research; however, none of the major theoretical contributions dealing with hurricanes [*Berkofsy*, 1957; *Kuo*, 1959; *Lilly*, 1959] have made use of the data collected within recent years. This is not surprising since the formidable task of describing the tropical cyclone from the vast amount of data available from the individual research flights is only in its beginning stages and no real attempt has been made to summarize the results of the individual case studies which have appeared primarily in the form of contract and preprint reports [*Blumen* and *Laseur*, 1958; *Laseur*, 1957, *Riehl* and *Gentry*, 1958; *Staff, N.A.R.P.* 1958]. These studies clearly indicate the increased importance which is being placed in the small-scale asymmetrical features of the hurricane which, when viewed from a large-scale viewpoint, is much more symmetrical than most atmospheric systems. The presence of the small-scale features within the hurricane has focussed inceased attention to radar and cloud photography as observational tools in investigations of the structure of these storms [*Jordan* and others, 1960, *Malkus* and others, 1960; *Senn* and *Hiser*, 1959].

The increased upper-air network, established in connection with the National Hurricane Research Project, has encouraged investigations of the large-scale atmospheric circulation patterns in the tropics. Considerable effort has been devoted to the preparation of forecasts of hurricane movement through numerical prediction techniques [*Hubert*, 1959b; *Hubert*, 1957; *Kasahara*, 1959ab] but so far the accuracy of these forecasts has not compared favorably with that demonstrated by experienced hurricane forecasters [*Hubert*, 1959]. It is not certain to what extent these shortcomings can be attributed to deficiences in the numerical prediction models since input data are very sparse over vast expanse of the tropical oceans. Quantitative techniques have also been employed in studying the horizontal and vertical transports of energy and mass within the troposphere in specially selected regions [*Ghangopahyaya* and *Riehl*, 1959; *Rex*, 1958; *Riehl*, 1959] and in evaluating frictional effects and flux of energy from the ocean surface in the vicinity of individual hurricanes [*Fisher*, 1958a; *Hubert*, 1959a, *Myers*, 1959]. The significance of these individual studies is difficult to judge at the present time but it appears rather certain that the quantitative approach will continue and that machine computations will become commonplace in the investigations of tropical cyclone development and movement.

A large number of investigations have been carried out during the past three years which can be grouped into a very broad classification as tropical climatology. Mean upper air data have been presented [*Gutnick*, 1958; *Hubert*, 1958; *Jordan*, 1958] and studies of the large-scale mean circulation features of the low latitudes have continued with increased emphasis on quantitative evaluations [*Krishnamurti*, 1959; *Palmén* and others, 1958; *Riehl* and *Malkus*, 1958]. Anomalies of the large-scale circulation features have been related to the frequency and tracks of hurricanes [*Ballenzweig*, 1959] and studies of tropical cyclone development on a world-wide basis have been made [*Ramage*, 1959]. The climatological approach has been used in developing techniques for forecasting the movement of tropical cyclones over periods of one to three days [*Jorgensen*, 1959, *Riehl* and *Sanborn*, 1958] and in the prediction of storm tides and surges [*Conner* and others, 1959]. A thoroughly checked set of tropical cyclone tracks for the Atlantic, Caribbean, and Gulf of Mexico areas for the period 1886–1958 has been published along with various statistical measures of interest to the hurricane forecaster [*Cry* and others, 1959]. Increased attention has been devoted to the sea-surface temperature distribution in the tropics and its relation to hurricane development, intensity, and movement [*Fisher*, 1958b, *Miner*, 1958, *Riehl*, 1959].

Investigations of the physics and dynamics of tropical clouds have continued to deal primarily

with clouds of the trade cumulus type [*Ackerman*, 1959; *Battan*, 1958; *Brown* and *Braham*, 1959]. However, some theoretical cloud physics work has dealt with hurricanes [*Woodcock*, 1958] and analyses are now being made of the cloud composition data collected in hurricanes and other tropical weather systems by the National Hurricane Research Project [*Braham* and *Neil*, 1957]. The gross features of cloud systems in the lower latitudes are being studied by means of extensive photographic programs [*Malkus* and others, 1960, *Riehl* and others, 1959], and considerable thought has been given to the planning and evaluation of cloud seeding experiments in hurricanes [*Braham* and *Neil*, 1958].

Although much of the data collected by the aircraft program of the National Hurricane Research Project during 1956–1958 were recorded on punched cards and were machine processed, much remains that could be done with this set of data in studies of the structure of weather systems and circulation features of the lower latitudes. In particular, synthesis of these data with those provided by the special upper air networks of the National Hurricane Research Project and the International Geophysical Year could conceivably occupy the primary attention of tropical meteorologists for many years to come. However, even with this wealth of observational material, new data collection programs are expected to begin in the near future. A Weather Bureau aircraft program beginning in 1960 utilizing more advanced data recording and processing techniques will be concerned with hurricanes and other tropical and subtropical systems during the summer and autumn months, and with middle latitudes systems during the winter and spring months. In addition, the satellite program promises to provide a new and challenging set of data for all meteorologists interested in atmospheric circulation patterns and weather distributions.

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Cloud Physics

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The boundaries of cloud physics appear to be widening at a tremendous rate. We may not only, with *Bergeron* [1960], distinguish between micro-, meso-, and macrophysics of clouds (corresponding in scale approximately to the terms micro-, meso-, and macrometeorology) but we also have to add physics of precipitation and physics of cloud modification. Since a very important tool, radar, has been added since World War II to meteorological research, we find that the major part of radar meteorology consists of cloud-physics investigations with radar as a specific tool. The scale of cloud physics thus reaches from studies of the behavior of individual water molecules in the all-important processes of condensation and droplet or crystal growth to planetary movements of the circulation patterns which set the stage for disastrous

tornadoes and snow or rain storms. The scale thus reaches from 10^{-4} centimeters to 10^{8} centimeters.

Analysis methods have to use in increasing number statistical and numerical methods, owing to the fact that it is no longer possible to consider the behavior of an average particle alone where the differential behavior of a population of nuclei, drops, crystals or precipitation particles must be understood.

Cloud physics, thus, as other physical sciences, has entered a new phase of research in the past few years. There is less and less room for revolutionary ideas or new theories, and an ever-increasing amount of work must be devoted to observational details and numerical analyses. We may compare the situation, for instance, with that of research concerned with the infrared radiation budget of the atmosphere. Here we are no longer satisfied with the knowledge of the gross transmitted or absorbed energy but we need to know the influence of selective absorption bands or even the influence of the edge effect of such bands. The analogy to cloud physics is that we are, for instance, no longer satisfied to know the total water content of a cloud, but we need to know how this water content is distributed in various clouds throughout the range of drop sizes and drop concentrations. Or in the study of precipitation mechanisms we are no longer satisfied knowing total rate of rain, but we want to know its areal fine structure. Or we have to study the life history of specific snow-crystal types. Finally in the research on cloud formation we are no longer satisfied to know that condensation occurs at the cloud base but we are interested in how many droplets form in various cloud types and even which nuclei of the aerosol population take part in the condensation process. The interest in origin and composition of aerosol as discussed by *Junge* [1958] is therefore great among cloud physicists. The influence of the aerosol spectrum on the cloud structure reveals most distinctly modern methods and progress through the repetition of *Howell's* [1949] pioneering work through computations of the growth of cloud drops by condensation using an electronic digital computer [*Neiburger* and *Chien*, 1960]. Here the influence of nuclei spectra, updraft velocity, and cloud base temperature on concentration and growth of cloud drops in various convective cloud types is most clearly illuminated; but, nevertheless, the authors find "that even with the electronic digital computer, the integration . . . is extremely time consuming." Experimental verification of these analyses still present unsurmountable difficulties. Qualitative data have been obtained in an interesting series of experiments using a giant expansion chamber [*Gunn* and *Phillips*, 1957].

This is the place to call attention to the proceedings of the First Woods Hole Conference on the Physics of Cloud and Precipitation Particles which was arranged by the Cloud Physics Committee of the AGU under joint Air Force—Navy sponsorship (*Artificial Stimulation of Rain*, 1957). The subject of the conference was divided into four main parts: (1) aerosols, their origin, distribution, and measurement, (2) condensation and coagulation; properties of liquid particles, (3) melting and freezing; properties of solid particles, and (4) crystal growth and nucleation. The value of the book lies in the numerous contributions to basic microphysics of clouds and precipitation and not in a discussion of topics that the erroneous title may suggest.

Research in meso- and macrophysics of clouds deals of necessity mainly with the collection and analysis of observational data rather than with the development of theories. We find theoretical treatments of the bubble-vortex model of convection [*Levine*, 1959] and of the three-dimensional lee wave [*Wurtele*, 1957]. An interesting analysis of cloud lines [*Kuettner*, 1959] explains their formation as a consequence of certain vertical wind and temperature gradients. It is shown that cloud line formation must be a global phenomenon which is in partial agreement with recent findings of *Malkus* and *Ronne* [1960] in the trade-wind region of the Pacific Ocean.

The main interest centers in the analysis of environment and life history of severe local storms as part of an intensive search into their mechanism. The present situation is illuminated by one expert's statement: ". . . one cannot overlook the strong suggestion that the make-up of thunderstorms in general and hailstorms in particular, involves an important ingredient not recognized today" [*Beckwith*, 1960]. While mesoanalyses of well-documented tornadoes are important milestones on our way to such under-

standing, they also seem to confirm this view: not even the masterhand of *Fujita* [1958a] was able to uncover the secret of the tremendous intensification of the Illinois tornado of April 9, 1953. This tornado started out as an appendix to a large hailstorm which covered about 100 sq mi, but within 20 minutes this mother hailstorm had degenerated and became only an appendix to the tornado. Tornado proximity soundings [*Beebe*, 1958ab], analyses of severe convective storms [*Donaldson*, 1958, 1959], characteristics of Denver hailstorms [*Beckwith*, 1957], and an analysis of the movement of large convective rainstorms in relation to winds aloft [*Newton* and *Katz*, 1958] are but a few examples of the intensive work carried out in this field. It appears that out of a great number of parameters one has to consider specifically the inflow and outflow characteristics of the storm, its migration and propagation velocity as well as those of its individual cells, the variations of instability and depth of the moist layer along the path in order to be able to obtain an analysis of the air circulation through the storm. Sometimes, indeed, nature herself eliminates a few parameters: a hailstorm in Seldon, Kansas, appeared not to have moved at all during two hours of uninterrupted hailfall which modifies the town and environment to a winter scene in mid summer [*Robb*, 1959]. Mesoanalyses of such storms should yield important keys regarding their circulation system which in this case must have been continuously supplied by the windsystem and could not have been tapped by the migratng storm.

A progress report on cloud physics has been published as a monograph by the American Meteorological Society [*aufm Kampe* and *Weickmann*, 1957].

The physics of precipitation has been discussed in a monograph of the American Meteorological Society [*Weickmann*, 1957]. It was also the subject of the Second Woods Hole Conference which like the First was planned and arranged by the Cloud Physics Committee of the American Geophysical Union under a National Science Foundation grant [*Weickmann*, 1960]. The conference was divided into five main parts: (1) Morphology of precipitation clouds and cloud systems, (2) Morphology of precipitation and precipitation particles, (3) Fundamental precipitation processes, (4) Hail formation, and (5) Artificial precipitation control. The papers given at the conference presented an extremely interesting discussion of processes occurring in all scales involved in the formation of precipitation from the synoptic scale down to the microphysics of the condensation and ice crystal process.

Two fundamental precipitation mechanisms are now well established: (1) The Bergeron-Findeisen process of ice-crystal growth within a supercooled water cloud, and (2) the coalescence process of selected large cloud droplets within an all water cloud. From an analysis of the raindrop spectrum on the ground both processes can be distinguished [*Blanchard*, 1953]. The Bergeron-Findeisen process yields large drops and small concentrations whereas the coalescence process yields small drops and large concentrations. Some precipitation mechanisms exhibit clearly one or the other mechanism. Continuous snow or rainstorms in a moderate climate, for instance, are mainly due to the former, whereas tropical orographic rains as in Hawaii or rain showers over the ocean are due to the latter mechanism. In a moderate climate the coalescence mechanism produces only drizzle rain [*Mook*, 1955]. Its efficiency is therefore dependent on the proper liquid water content and on the presence of particles of a certain critical size whose collection efficiency is large enough to grow within the lifetime of the cloud to a precipitation particle. It is therefore clear that quite a number of investigations deal with the problem of drop collision and collection efficiency [*Schotland*, 1957; *Kinzer* and *Cobb*, 1958]. While it was considered so far that the presence of giant nuclei in the aerosol spectrum was the critical condition [*Woodcock*, 1957], *Squires* and *Twomey* [1960] showed convincingly that the nuclei concentration is the prime controlling characteristic. Investigations about the concentration of large drizzle droplets in clouds, as those by *Brown* and *Braham* [1959], over the ocean and over the land will help to clarify this question.

Of special interest of course are types of precipitation in which both mechanisms are active. Such are particularly showers and thunderstorms and all other types of rain with instability showers embedded, or intensive orographic lifting. Investigations by *Blanchard* [1957] and *Todd* [1960] of raindrop distributions as well

as the theoretical considerations given in an interesting paper by *MacCready* and others [1957] illuminate these cases.

The precipitation mechanism in thunder- and hailstorms is being studied using radar [*Morris*, 1957; *Braham*, 1958]. Ever since *Battan* [1953] discovered that first echoes in thunderstorms may start below the freezing level (*Workman* and *Reynolds* [1949] had found the first echoes above the freezing level), the question where the precipitation process starts has been unsettled. There is little doubt that it may start throughout the whole depth of the cloud, especially in the mature stage in which large particles are found from the base to the anvil. During the developing stage, however, for which first echo observations are valid, a certain preference may be found for the coalescence process whereby warm-base temperatures (high liquid content) and small concentration of condensation nuclei will favor first echo formation below the freezing level. With regard to the question regarding the Bergeron-Findeisen mechanism or the coalescence mechanism, a true statement seems to be that the ice phase is of secondary importance for the onset of precipitation but of prime importance for the efficiency of the precipitation mechanism. Soft hail formation increases the efficiency several times over a pure water process with regard to the water swept out from the cloud [*Weickmann*, 1957; *Douglas*, 1960].

Investigations in the macroscale deal essentially with studies of the moisture supply and water budget of storms [*Wexler* and *Atlas*, 1958; *Bradbury*, 1957]. These investigations are of great importance since they enhance our knowledge of the efficiency of the precipitation mechanism and illuminate the question: how much of the water brought into the storm is being precipitated? They also lay the ground work for the very interesting attempts to compute the large-scale rainfall pattern [*Smebye*, 1958]. With the assumption (among others!) of 100% efficiency, that is, all the vapor that condenses falls out, the agreement between the computed and observed large-scale patterns is as impressive as the disagreement on smaller scales. There can, however, be no doubt that methods and computations will become much refined in the future as soon as expressions have been worked out suitable for electronic computers [see, for instance, *Smagorinsky*, 1960].

As our understanding of the natural precipitation mechanisms progresses we find that the rate of precipitation is above all dependent on the rate of updraft, that is, on the mechanism which liberates the precipitable water, whereas the concentration of particles which sweep out the water is of secondary significance. It will be one of the future tasks of cloud physics to determine the efficiency of the various precipitation mechanisms in sweeping out the water furnished by the updraft [*Wexler, 1960*].

With respect to the efforts in cloud modification a shift in the emphasis is to be noted. Fewer and fewer publications appear as newspaper headlines and more as sound scientific research. The publication of the results of the so-called ACN (artificial cloud nucleation) activities of the Army, Air Force, Navy, and the Weather Bureau was a milestone for cloud and weather modification research [*Meteorological Monographs*, 1957]. The basic result was that large-scale modifications of weather have been unsuccessful, or, rather, that the effects were below the level of significance over the time interval of the experimental period. Only small-scale projects were successful like the dissipation of subcooled stratus or the initiation of precipitation through water seeding in tropical cumuli.

A statistical evaluation of large-scale commercial seeding projects has been accomplished under the auspices of the President's Advisory Committee on Weather Control [Final Report, vol. I and II, 1957]. The Committee concludes: "(1) The statistical procedures employed indicated that the seeding of winter-type storm clouds in mountainous areas in western United States produced an average increase in precipitation of 10 to 15% from seeded storms with heavy odds that this increase was not the result of natural variations in the amount of rainfall. (2) In nonmountainous areas, the same statistical procedures did not detect any increase in precipitation that could be attributed to cloud seeding . . ." In the second volume the statistical methods and examples are given. It is satisfying to read the first recommendation of statistician Thom [*President's Advisory Committee*, 1957] who has conducted these painstaking

evaluations: "A physical experiment on a simple orographic target is greatly needed, not only to check our results, but to determine exact physical increases due to seeding under known conditions." Thom states further: "Our feeling is that . . . the nuclei count at realistically effective levels may be much less than now thought."

While on the basis of these uncertainties too much emphasis has been placed on statistical design and evaluation of seeding projects, presently at least two seeding projects—the Santa Barbara Project and the Skyfire Project—are being evaluated by competent cloud physicists and statisticians. [*Todd*, 1960; *Project Skyfire*, 1957]. A similar small-scale project is the cumulus seeding project of the University of Arizona [*Battan* and *Kassander*, 1960]. It appears that the joint design and evaluation of cloud seeding projects by statisticians and physicists is the ultimate approach to this complex problem, and an approach which is very much in the spirit of the so-called Skyline Conference (National Academy of Sciences, Pub. no. 742, 1959) on the design and conduct of experiments in weather modification.

To this reviewer one of the most important conclusions arrived at is expressed in the following sentences: "In weather modification experiments, the role of randomization is important and was recognized as such at the Conference. However, randomization is no universal panacea, for no statistical refinement can be a substitute for a poorly designed physical experiment." In that sense, probably most of the past large-scale rainmaking experiments in the United States were poorly designed (with a few noticeable exceptions, for example, the Weather Bureau ACN Project, *Hall* [1957]. The crux of the matter is, of course, that of necessity large-scale experiments where the seeding agent is left to the winds, are *a priori* 'poorly designed' in view of the fact that the only certain correlation is between rate of precipitation and rate of updraft, and not between rate of precipitation and the concentration of precipitation particles, the latter being the only parameter that can be changed.

While the *experimentum crucis* in this matter still lies ahead of us, it seems that we have come already a long way since Langmuir's days, where we find the statement: "The particular merit of this statistical approach to problems of this kind is that it is possible to find out whether a thing is significant and, therefore, whether or not a hypothesis can be verified, without understanding the nature of the physical phenomena underlying the effect. For example, it is not necessary in advance to know just how silver iodide gets into the clouds, nor all the phenomena involved in rainfall" [*Langmuir*, 1953]. The reader is finally referred to an excellent summary of the physical side of cloud modification [*McDonald*, 1959] and to the papers and comments of the session *Artificial Precipitation Control* of the Second Woods Hole Conference which point also to future potentialities of large-scale seeding. Of course, any large-scale seeding action will always be connected with a tremendous logistic effort which is likely to make the whole undertaking unrealistic [*Wexler*, 1958].

The stepchild of cloud-physics research is instrumentation. Still, no satisfactory solution has been found for the determination of the most elementary cloud parameters as droplet spectrum, droplet concentration, or liquid content. Aircraft investigations are not only hampered by the great speed and pressurization of the craft but also by the air-traffic regulations which make quick altitude changes and cloud traverses virtually impossible. It appears that modern instrumental techniques cannot be introduced without considerable expenditure of funds and without an organization which is able to concentrate on such developments. Apparently the planned Institute of Atmospheric Research could be such an organization [*Committee on Meteorology*, 1958].

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The raw material for climatological research is ever-increasing in the United States. About 28,000 pages of data are published annually. Interests exists, of course, not only in local but in world-wide conditions. This has resulted in the publication of the third supplement to World Weather Records, covering the interval from 1941 to 1950 [*U. S. Dept. Commerce*, 1959a]. This issue includes some new long series and revisions of older ones. As first digest of all these data new climatological maps of the United States [*U. S. Dept. Commerce*, single sheets] and of various parts have been prepared [*Ackermann* and others, 1958] as well as a complete revision of the Climates of the States [*U. S. Dept. Commerce*, 1960a]. The data have also served for the compilation of climatic tables intended for industrial uses in the heating and air conditioning industry [*Amer. Petroleum Inst.* 1958, *Fluor Products Co.*, 1958] A major continuing effort has been the charting of climatic elements over the world's oceans and water ways for the guidance of mariners [U. S. Navy; U. S. Dept. Commerce, 1959b, 1960b].

Climatographic studies of damaging and destructive weather events have included freezes (10) [*Frederick* and others, 1959], tornadoes [*Wolford*, 1960; *Lee*, 1958], and hurricanes [*Cry*

and others, 1959; *Haggard*, 1958, 1959]. Much attention has been paid to the problems of evaporation, evapotranspiration, and drought, as a natural consequence of the second major drought disaster in two decades [*Kohler* and others, 1959; *Thornthwaite* and others, 1958; *Horn* and others, 1957; *McGuire* and *Palmer*, 1957; *van Bavel* and *Carreker*, 1957; *van Bavel*, 1959; *Brunk*, 1959; *Decker*, 1957, 1958; *Harbeck* and others, 1958, *Hargraves*, 1958]. The probability of dry conditions have been studied and various rational systems of estimating supplemental irrigation needs for agriculture have been developed. The debate on how to reduce climatological and evaporation data into soil moisture and plant needs continues but a gradual rapprochement of various schools of thought can be discerned.

As elsewhere in the world, considerable effort has been devoted to the understanding of the interactions between soil and atmosphere. The measurements of soil temperature have improved [*Blanc*, 1958] and a comprehensive survey of all existing sources has been made [*Chang* 1957, 1958]. Soil moisture measurements are still suffering from inadequate instrumentation but use of neutron diffraction meters has opened a new avenue. For the agricultural regions useful series of data are appearing [*Pengra*, 1959]. The microclimatic environment of special areas, such as the desert [*Dodd* and *McPhilimy*, 1959] and the northeastern deciduous forest [*Ross*, 1958] has been explored.

The more uncommon aspects of clouds and hydrometeors have attracted a great deal of attention. The idea of a detailed cloud census is being pursued in various sections and the relations of coverage and types to precipitation are being studied [*Chagnon* and *Huff*, 1957]. Similarly, further work has been done on the distribution of rainfall intensity in the thunderstorms [*Chagnon*, 1957]. The use of radar to obtain better climatological coverage of storms, especially in mountainous areas and between stations has made progress [*Blackmer* and *Morgenstern*, 1958]. Attempts at interpretations of series of radarscope photographs to improve climatological isohyetal charts have been made but more experience and longer records are needed. Some interesting special studies on frozen precipitation have also been published. One is a comprehensive monograph on hail size and distribution in the United States [*Hull*, 1957]. Another deals with meteorological and geographical aspects of glaze. This element is of major importance for power and communication lines and all traffic, especially on highways. A glaze belt extends from the Rocky Mountains through the Central States to the Middle Atlantic States. In this area, glaze of 6-millimeter thickness can be expected two out of three years [*Bennett*, 1959].

The relation of weather types in narrow geographical zones [*Calef* and others 1957] and the broader aspects of circulation patterns to climate have found attention. The use of climatic analogs in various parts of the world has a practical aspect from the point of view of use of clothing, material, and equipment and its maintenance [*Thompson*, 1950, 1958, 1959], especially in the tropical zone. The latter with its great variety of climates provides fascinating climatic problems. A new attempt at definitions in this realm includes all areas where the coldest month averages at least 18°C and distinguishes five circulation areas in it: predominantly influenced by westerlies, the trade zones, the monsoon regions, the doldrums, and the hurricane areas [*Blumenstock*, 1958]. The increased emphasis on the latter sector has already been cited. Climatological aids for the forecasters on hurricane motion have also been developed [*Riehl* and *Sanborn*, 1958]. In the extra-tropical region the dynamic climatology of pressure centers has disclosed the tendency for cyclogenesis and anticyclogenesis to be particularly frequent in the latitudes of the peak of the westerlies at the 700 mb level. The average life span of mid-latitude centers was found to be about 5 days [*Klein*, 1958].

Modern analytical and statistical methods have been applied to climatological problems. In many cases this was materially aided by large-scale use of electronic computers. Particularly useful has been the expansion of these procedures to vector quantities such as winds or displacements of pressure systems [*Crutcher*, 1958a]. Analytical procedures were particularly useful in assessing uneven data sources such as ships' observations [*Rosenthal* and *Gleason*, 1958; *Rosenthal*, 1959; *Schell*, 1959]. The conventional statistical procedures as well as specially elaborated applications of various functions, for example the incomplete gamma function

and extreme-value distributions, [*Gumbel*, 1958] have been applied to such diverse elements as daily and monthly temperatures [*Enger*, 1959ab], their space distributions [*Henson*, 1959], topographic relief relations [*Dickson*, 1959], drought [*Friedman*, 1957], freeze [*Friedman*, 1959; *Thom* and *Shaw*, 1958; *Thom*, 1959a], rainfall rates and extremes, as well as the probability of occurrence [*Thom*, 1959b, *Russak* and *Esley*, 1958, *Friedman* and *Janes*, 1957]. Further extension of statistical procedures to description of synoptic processes and, finally, application of discriminant function to whole climatic regimes [*Shorr*, 1959; *Crutcher*, 1959] has resulted in new numerical approaches to old climatological regimes [*Shorr*, 1959; *Cruthcher*, 1959] has resulted in new numerical approaches to old climatological problems.

New observational data and source studies [*Quiroz*, 1959] have permitted also a particularly vigorous attempt to chart and analyze the climatic conditions of the upper air. These include items of direct interest to aviation at low levels, such as ceilings [*Hunter* and others, 1959] and methods to obtain their frequency distribution [*Spreen* and *Solomon* 1958] as well as the vertical distribution of temperatures, humidities, densities and winds [*Ratner*, 1959; *Crutcher*, 1958b] and flow characteristics at higher levels [*Lahey* and others, 1959]. Of particular interest has been the distribution of upper winds because of their relation to radioactive fallout. Wind data have been compiled to 80,000 feet [*Charles*, 1957] and analyses of temporal and spatial correlations have been computed [*Court*, 1958, *Charles*, 1959]. Simple procedures for obtaining dosage patterns on the basis of climatological data are available [*McCabe* and *Potter*, 1959].

Although stratospheric values of temperatures are still afflicted by considerable observational errors an interesting attempt has been made to obtain the diurnal variation. This shows the following approximate amplitudes: 200-150 mb-levels, 0.15 to 0.2°C; 100 mb-level, 0.2 to 0.25°C; and 50 mb-level, — 0.35°C [*Chu*, 1959].

For the dynamics of the subtropical zone the behavior of the tradewind inversion is quite important; it has become better known [*Gutnick*, 1958]. Also for comparisons with hurricane conditions reasonably reliable upper air averages have now become available in the Gulf of Mexico area [*Hebert* and *Jordan*, 1959].

For problems of radio-wave-propagation climatological data of the refractive index over large areas have been calculated from the soundings and analyzed in charts [*Bean* and *Gallet*, 1959, *Bean* and *Ozanich* 1958].

The first climatological use has also been made of rocket and satellite data by providing design engineers with a model atmosphere. Heretofore at higher elevations atmospheric models were derived from indirect observations and theoretical deductions. The 1959 model of temperatures, densities, and molecular properties deviates quite notably above 53 km from earlier models. Up to 700 km, a fairly definitive picture emerges but some estimates can be made to 1000 km [*Minzner* and others, 1959].

Climatic cycles, fluctuations and trends at the surface have remained a target for research. Harmonic analyses have contributed to better knowledge of the annual fluctuation in the arid zone [*Bryson*, 1957]. An attempt of power spectrum analysis of a long bench-mark station temperature and precipitation record on the east coast of the United States revealed some power in cycles of the length of the long waves in the westerlies, and rhythms probably related to index fluctuations. Of the longer cycles a two-year cycle is well pronounced, a weak tendency for a sunspot rhythm in the temperature exists and considerable power resides in a multidecade variation [*Landsberg* and others, 1959]. The trend toward warming has still been maintained. The means of two recent consecutive 25-year periods differ by a small but significant amount of about 0.5°C, somewhat more in the north and less in the south of the country. Rainfall has not changed materially [*Landsberg*, in press]. Search for older records is continuing [*Havens*, 1958] and analysis of the most reliable series is in progress. Particularly noteworthy are the circulation changes that have been made probable as coincident with the Atlantic-European shifts [*Schell*, 1957, *Fay*, 1958]. A remarkable finding has been the rise of mean temperature of several degrees for the Little America area of the Antarctic since 1911 [*Wexler*, 1959].

A new hypothesis of ice ages [*Ewing* and *Donn*, 1958] predicated on the flow of warm oceanic water into the Arctic basin, the melting

of the ice, the subsequent increase of snowfall in subarctic continents, followed again by freezing of the Arctic Sea is intriguing but has been by no means generally accepted [*Livingstone*, 1959].

The local relations of climatic conditions to life processes have been investigated with fair success for autochthon and crop plants and applied to crop planning and yields [*Caprio*, 1957; *Wang* and *Suomi*, 1959, *Newman* and *Wang*, 1959, *Riley* 1957]. The doctrines of climatic environment and adaptations of domestic animals and humans have become well defined [*Lee*, 1958] but the relations to human disease remain fairly intractable although statistical relations of acute weather events and deaths are significant [*Kutschenreuter*, 1959].

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Numerical Weather Prediction

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For the purposes of this summary we may subdivide the work on numerical weather prediction into three principal categories: (I) construction of idealized models of atmospheric motions, (II) use of models for the study of particular physical phenomena, and (III) mathematical analysis of the properties of the finite-difference equations.

Construction of models

Earlier work dealt primarily with the low-frequency (planetary) flows in the atmosphere.

The quasi-geostrophic constraint was introduced to filter out the complicating high-frequency 'noise' motions, and the freedom in the vertical was reduced by various devices. In the last triennium refinements have been introduced into the vertically truncated equations to remove physical inconsistencies, such as their failure to conserve energy, and to extend the geostrophic formalism to cover low-frequency but non-geostrophic motions [*Eliassen*, 1956; *Lorenz*, 1957a]. The so-called balance equations, to which this extension gives rise, are highly implicit and until recently had been solved numerically only for two-dimensional barotropic flows [*Charney*, 1960a]. A method of solution has now been found and tested for the general baroclinic atmosphere [*Charney*, 1960a]. However, this method, while it may be useful for theoretical purposes, is complicated and time-consuming, and it appears likely that with sufficient care one can instead solve the primitive Eulerian equations of motion with the hydrostatic approximation [*Charney*, 1955; *Eliassen*, 1956]. Successful integrations of such equations have now been carried out on a hemispheric scale by *Smagorinsky* [1958] and *Phillips* [1959a].

In the theoretical analysis of large-scale atmospheric motions *Lorenz* [1957b] introduced the novel simplification of retaining only a few terms in the expansion of the geostrophic stream-function field in orthogonal (harmonic) functions. The resulting equations conserve energy and reduce to a small set of non-linear ordinary differential equations whose solution can readily be obtained by numerical means. With the aid of these equations one may study a variety of non-linear phenomena relevant to large-scale atmospheric system, such as the zonal index cycle, or 'vacillation,' in which energy is exchanged among various harmonics of the motions.

Applications to particular problems

The general circulation—The quasi-geostrophic formalism has found successful application in the study of the general circulation of the atmosphere. Using a highly simplified, two-layer, quasi-geostrophic, β-plane model containing energy sources and sinks, *Phillips* [1956] was able to account for many important features of the zonally averaged circulation of the atmosphere and its perturbations. This work was extended by *Smagorinsky* [1958, 1960a] to more realistic flows on a hemisphere by numerical integration of the primitive equations. Integrations for periods up to sixty days revealed striking similarities to actual atmospheric conditions. An attempt has been made to give a theoretical explanation for the mean flow patterns observed in Phillips's and Smagorinsky's experiments by means of a second order perturbation technique [*Charney*, 1959]. Integration of a 4-level quasi- geostrophic model, containing some non-geostrophic effects as well as friction, heating and eddy conduction, were performed by *Kuo* and *Nordö* [1959] for a hemisphere. In four days a randomly disturbed zonal circulation developed into a pattern resembling a possible atmospheric state. It has now become evident that the electronic computing machine has taken its place beside the rotating tank as an important experimental device for the study of atmospheric motions.

A second approach to the study of the general circulation was introduced by *Bryan* [1959] who applied *Lorenz's* [1957b] truncated-orthogonal-expansion technique to obtain a set of 13 ordinary differential equations describing the flow of a 2-layer, quasi-geostrophic model with heat sources and a variable static stability. The solutions indicated many properties noted in rotating tank experiments and in theoretical studies of large-scale motions. Further applications of this kind to the general circulation have recently been carried out by *Lorenz* [1960].

Energy exchange in barotropic systems—The vacillation phenomenon, first observed in a rotating tank by *Hide* [1953], was found in a numerical experiment concerned with the calculation of the growth of finite-amplitude unstable perturbations of a parallel barotropic flow [*Charney*, 1959]. This work has been continued and considerably extended by *Platzman* and *Baer* [1958] and *Baer* [1958] using a greatly refined technique for integrating the barotropic vorticity equation. An interesting by-product of their work was the calculation of the power spectrum of the flow at the high-wave number, low-energy end. In this region the spectral energies appear to approach the Kolmogoroff five-thirds law. Similar results as regards vacillation have been obtained by *Lorenz* [1957b] with his very simple model.

The stability properties of barotropic flow and the finite-amplitude interactions of the perturbations with the mean flow were also investigated by *Holl* [1958].

Introduction of energy sources—It is important, both for general circulation experiments and for studies of individual flow systems, to introduce energy sources and sinks. Several numerical experiments were performed by *Smagorinsky* [1960b] in which he took into account the transport of water vapor, the formation of cloud and the release of the latent heat of condensation [see also *Smagorinsky*, 1955, 1956]. *Kaplan* [1959] developed a method for calculating heat transfer by infra-red radiation in the atmosphere for use in numerical models. *Reed* [1958] made an attempt to incorporate non-adiabatic effects in the Fjörtoft graphical prediction model.

Small-scale motions—Numerical methods are increasingly being applied to smaller-scale phenomena. Using the primitive equations and the long-wave approximation for a homogeneous fluid, *Platzman* [1958a] calculated the tidal motions produced in Lake Michigan by an intense fast-moving squall line. *Sasaki* [1959] began some numerical experiments to predict the evolution and motion of the squall line itself. *Malkus* and *Witt* [1959] calculated the evolution of a buoyant element of air in a gravitationally unstable atmosphere, as a first attack on the problem of cumulus development. *Estoque* [1959] began a study of time variable physical processes in the atmospheric boundary layer by calculating the variations of wind, temperature and heat and momentum fluxes in the boundary layer produced by a periodically varying ground temperature. A noteworthy result was his prediction of the wind maximum that is observed to occur at midnight in the upper part of the boundary layer. *Birchfield* [1957, 1958] and *Kasahara* [1958, 1959] developed techniques for predicting the translatory motion of a hurricane, regarded as a small-scale vortex imbedded in a larger-scale steering current.

Mathematical analysis of the finite-difference equations

Properties associated with the lattice structure of the finite-difference equations: computational stability, truncation error, and convergence—The truncation errors and convergence properties of several finite-difference formulations of linearized versions of the primitive or vorticity equations or both were investigated by *Platzman* [1958b], *Mihaljan* [1958], *Gates* [1959], and *Phillips* [1959a]. The truncation error and the filtering effects arising from the use of various finite difference analogues of the Laplace operator were discussed by *Shuman* [1957b] and *Ogura* [1958]. A method of controlling truncation error by the introduction of a viscosity coefficient depending on the deformation tensor was proposed by Charney and was found to give good results in some unpublished numerical experiments conducted at the Institution for Advanced Study and in *Smagorinsky's* [1960a] general circulation calculations.

In the earlier-mentioned papers by *Platzman* and *Baer* [1958] and *Baer* [1958] finite Fourier series were used for inverting the Laplace operator, and truncation errors were controlled by systematically suppressing higher order harmonics arising from the advection terms in the vorticity equation. A rationale for the application of this very effective smoothing technique was given by *Platzman* [1958c], who also made a general study of the non-linear properties of the vorticity equation by expansion of the solution in spherical harmonics [*Platzman*, 1959].

Two noteworthy results were obtained for the non-linear finite-difference equations: *Montvila* [1959] proved convergence for the (uncentered) finite-difference, non-linear, two-dimensional vorticity equation and gave error estimates; *Phillips* [1959b] demonstrated a kind of computational instability caused by spurious non-linear interaction among (centered) finite-difference wave components and developed a smoothing technique which appears to eliminate this instability.

Boundary conditions—When, as is often the case, integration must be performed for limited regions of the atmosphere, it becomes necessary to specify boundary conditions at a fluid boundary. The conditions proposed by *Charney, Fjörtoft*, and *von Neumann* [1950] for the two-dimensional vorticity equation, and proved only heuristically, are (1) that the stream function must be specified at all boundary points, and (2) that the vorticity must be specified at inflow points. *Benton* [1958] showed that if Con-

dition (2) is removed a unique solution will still exist providing it can be represented as a convergent power series in time. It is, however, doubtful that such an expansion is possible, especially in view of *Sensenig's* [1958] proof that the boundary Conditions (1) and (2) do in fact imply existence and uniqueness in the infinite half-plane.

It is plausible on physical grounds that similar conditions hold for the primitive equations. In the case of an atmosphere consisting of several homogeneous incompressible layers a heuristic proof that the normal velocity component should be specified at all boundary points and the *potential* vorticity at inflow points has been given by *Charney* [1960b].

The balance equation—Iterative methods for solving the balance equation

$$\nabla\cdot(f\nabla\psi) + 2(\psi_{xx}\psi_{yy} - \psi_{xy}^2) = \nabla^2\phi$$

for the stream function ψ when the geopotential ϕ is given (f is the Coriolis parameter) were proposed by *Shuman* [1957a] and *Arnason* [1958], and shown by trial to converge, providing the criterion $f^2 + 2\nabla^2\phi > 0$ is satisfied. The physical necessity of this criterion has, however, not been demonstrated.

The practical utilization of numerical weather-prediction methods gives much insight into the properties and limitations of the various idealized models of the atmosphere. An excellent review of the results obtained with various hemispheric barotropic models by the Joint Numerical Weather Prediction Unit of the U. S. Weather Bureau has been given by *Cressman* [1958, 1959].

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Past Ice Ages

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Direct research into past climates which emphasizes the Pleistocene Ice Age, about which so much more is known than those preceding it, can be divided into essentially empirical determinations of climatic chronology and theoretical explanations of causes of climate change.

Climatic chronology—The central problem here has been the attempt to determine a re-

liably documented record of climate as far into the past as possible. Unfortunately the nature of the data often is such as to require interpretation, sometimes open to question, in the establishment of climatic chronology.

The taking and studying of deep-sea cores continues to be one of the best sources of paleoclimate information. The Lamont Geological Observatory of Columbia University now has the largest such core collection which has been taken from the North, South, and Equatorial Atlantic Ocean, the Caribbean and Mediterranean Seas, the Gulf of Mexico, and the Eastern Tropical Pacific Ocean. In cores from all but the Pacific, when the sedimentary record was normal and undisturbed, *Ewing* and *Donn* [1956] first described a sharp break which indicated an abrupt warming of the Atlantic surface waters about 11,000 years ago and interpreted this to indicate the end of the Wisconsin glacial stage.

More recently, *Broecker, Ewing,* and *Heezen* [1960] summarize a considerable body of evidence indicating a 6 to 10°C warming of the Atlantic surface waters during an interval of less than 2000 years and that the midpoint of this change was within 300 years of 11,000 years ago. In this paper, the authors refute the conclusion of *Emiliani* [1957] that this change was transitional over a period of 8000 years. The change in the Atlantic surface waters makes a noteworthy contrast with that of the Pacific where far less conspicuous temperature changes occurred [*Emiliani,* 1955]. Ericson (personal communication) reports that one core from the North Atlantic Basin may have penetrated the Pleistocene-Pliocene boundary in view of the sharp extinction of a warm Pliocene fauna.

The climatic record from the Pacific Ocean has been largely the product of the taking and studying of deep-sea cores by the Scripps Institution of Oceanography where marine climatic trends have been extended through most of the Cenozoic owing to the generally thinner sedimentary record [*Arrhenius,* 1959; *Bramlette* and *Riedel,* 1959; *Riedel* and *Bramlette,* 1959].

Fairbridge [1959, 1960] has attempted to establish a climatic chronology of the Pleistocene Ice Age on the basis of eustatic stands of sea level using geochemical dating and temperature criteria, varves, pollen, etc., for the Wisconsin and extrapolating from different approaches for times beyond effective radiocarbon range.

Excellent continuous continental climatic records covering both the transition from Pliocene to Pleistocene glacial times and the glacial-interglacial fluctuations of the Pleistocene have been and are being studied from long cores taken from glacio-pluvial lakes. These have been interpreted on the basis of pollen and radiocarbon data, sedimentation rates, and geochemical analysis. Recent reports by *Clisby* and others [1959], *Axelrod* [1957], and *Smith* [1959] continue the immediately preceding methods and results of *Clisby* and *Sears* [1956], *Foreman* [1956], and *Stearns* [1956]. The abrupt warming noted in the oceans about 11,000 years ago has also been described for pluvial lakes by *Broecker* and *Orr* [1958].

IGY parties in the Arctic and Antarctic have obtained data bearing on the climatic history of these areas. The method of thermoluminescence described by *Zeller* and others [1957] indicates tentatively that no major temperature change occurred in Antarctica for at least 170,000 years [*Crary,* 1959]. A large number of cores up to 200 cm long have been taken by parties on IGY ice-floe stations in the Arctic. The preliminary description of this material [*Hunkins,* 1959] indicates that significant climatic interpretations are possible.

Theoretical work—Emiliani and *Geiss* [1957] reported a theory of Pleistocene and possibly older ice ages from a combination of terrestrial and astronomic factors. These authors make the rather dubious proposal that orogenesis, preceding glaciations, would increase the Earth's albedo, thus decreasing temperatures. Below a certain threshold temperature astronomical causes of temperature variation would then become operative. They believe that the effects of plastic ice flow and crustal warping would produce necessary time lags and that a major control of precipitation was the evaporation from the North Atlantic Ocean which was cut off when the North Atlantic froze over north of the present 10°C winter isotherm.

Schell [1957, 1958] proposed that the Pleistocene Ice Age could only occur from a small but continuous decrease in solar radiation such that a steep latitudinal temperature gradient would result from a slight cooling of equatorial regions and a strong cooling of polar regions. This

effect would produce an increased circulation characteristic of an ice age. A secondary ocean control would be superimposed.

Ewing and *Donn* [1958, 1959] extended their original theory [1956] which proposed that the primary cause of Pleistocene glacial-interglacial fluctuations was the oscillation of the surface of the Arctic Ocean between an ice-free and an ice-covered state, respectively. The 1958 extension explained the Pleistocene glaciations in the southern hemisphere as a consequence of the global refrigeration resulting from northern hemisphere glaciations which decreased the Earth's albedo from increased snow cover in glaciated areas and increased cloud cover in pluviated areas. Pluviation of presently arid regions is explained from the equatorial migration of present storm belts as a consequence of the equatorward extension of polar air. From interpretations of paleotemperatures afforded by the faunal content of deep-sea cores, *Ewing* and *Donn* [1959] based on a previous study by *Ericson* [1959], gave estimates of possible glacial-stage temperatures of the Northern North Atlantic and Arctic Oceans.

A recent, fairly comprehensive survey of the subject of paleoclimates and a description and criticism of the method of study has been made by *Durham* [1959]. In general theories of climatic change have chiefly involved one or a combination of the following causes: variations in solar output, variations in radiation received by the Earth owing to geometric effects or cosmic clouds, changes in atmospheric carbon dioxide, continental drift, polar wandering, ocean control, and variations in the relief of the continents.

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Statistical Methods

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Statistical methods are used in meteorological investigations of many types ranging from those concerned with the description and understanding of atmospheric processes, such as in studies of the general atmospheric circulation, to the design of meteorological experiments, such as those of importance in cloud seeding, to their use in prediction of the future state of the atmosphere. In this summary only statistical methods as used in meteorological prediction are considered.

The first systematic examination of the application of statistical methods to weather forecasting was undertaken by *Wadsworth* and others [1948], during and just after World War II. Methods presently being applied and extended are largely outgrowths of this work. By the beginning of 1957, the capabilities of high-speed electronic computers had been exploited to treat the meteorological prediction problems by standard linear regression analysis using systems of large numbers of variables. Principal attention during the past several years has been focused on techniques for extracting the principal predictive content from large systems of highly correlated variables which are characteristic of the atmosphere. Extensive application has been made of stepwise regression procedures first used in meteorology by Bryan (unpublished manuscript, special techniques in multiple regression, 1944) and modified and extentensively developed by *Miller* [1958], and techniques of factor analysis principally applied by *Lorenz* [1959].

The period witnessed a growing realization of the necessity for bringing into closer relation dynamical and statistical approaches to meteorological prediction. Initial attempts were made to devise statistical prediction procedures based on systems of variables suggested by the dynamical equations as done by *Cooley* [1959] and *Sellers* [1957]. Conversely, there has been a growing interest among those concerned with the application of dynamical prediction techniques in methods of treating the uncertainties in atmospheric information and their effects on the prediction process. Perhaps the ultimate limitation to meteorological prediction rests in the uncertainties in the initial state of the atmosphere. The manner in which these uncertainties are propagated by means of dynamical prediction mechanisms are now being considered, as, for example, by *Thompson* [1957] and *Woodbury* [1959]. The attempt to deal with these uncertainties and the specification of their magnitudes and distributions is being attacked by statistical means through the multiple discriminant analysis approach of *Miller* [1959].

The two most prominent concerns now occupying those engaged in statistical weather prediction are related to effective means of representing and incorporating non-linear processes in statistical prediction schemes and methods of extracting and applying the uncertainty content of meteorological information. The preoccupation of the early part of this period with means of handling large numbers of correlated variables and devising stable statistical systems has therefore shifted to considerations of alternative means at systematizing the non-linear atmospheric processes. Promising results appear to have been obtained by application of statistical regression procedures in a Lagrangian as contrasted with an Eulerian coordinate system. In the Lagrangian coordinate system both independent and dependent variables are specified with respect to atmospheric phenomena and not to geographically fixed coordinates. Statistical operators have been devised for predicting the motions and intensities of atmospheric phenomena themselves as, for example, in the hurricane studies of *Veigas* and others [1959]. The shift to a Lagrangian coordinate system, in which independent variables are taken relative to meteorological phenomena, is one step in the

direction of attempting to consider those features of atmospheric systems which appear to exhibit a linear behavior and from which it is possible to derive subsidiary information which in an Eulerian coordinate system exhibits a highly non-linear behavior. Attention was also devoted to the consideration of techniques which by-pass the restrictions of the linear regression approach and which enable one to handle discrete variables. The most promising work of this kind is that presently being pursued by *Miller* [1959] in a stepwise form of multiple discriminant analysis.

The growing attention to the uncertainty characteristics of atmospheric information has led to a serious re-examination of the application of weather information to actual operations. There has been a growing realization on the part of meteorologists that for effective application of weather information to operations it is not sufficient, in view of the uncertainties, to provide only the expected values of meteorological events, but to provide operators with as complete a set of information about the probability distribution of atmospheric events as possible so that operating decisions can be made on the basis of risk. A number of investigations of the best manner of providing such information have been conducted in the past few years, notably by *Gringorten* [1959], *Borgman* [1959] and *Roberts* and *Bruch* [1959].

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Satellite Meteorology

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Introduction

Since large-scale meteorological problems involve events on a global scale, the artificial satellite, with its capability of observing the whole planet in a short time, is a unique platform from which valuable world-wide meteorological observations can be supplied.

There are many ways in which meteorological

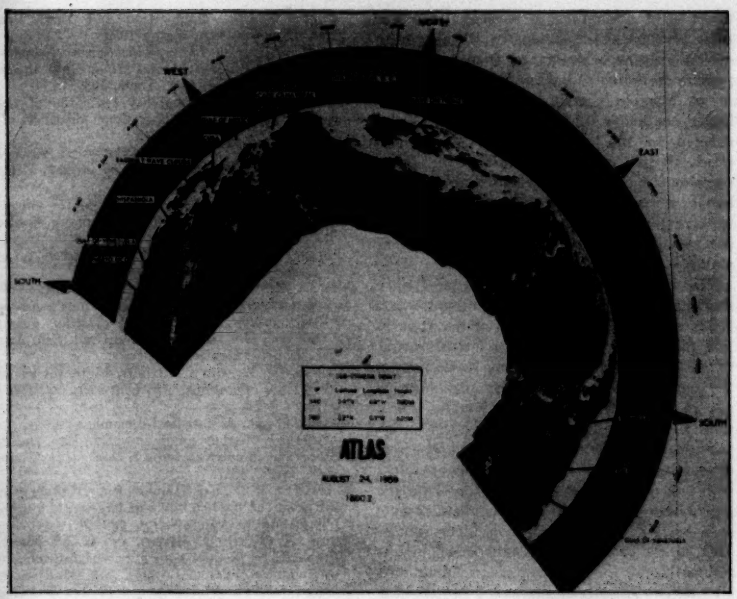

FIG. 1—Mosaic assembled from photographs taken from an altitude of about 400 miles

measurements from satellites will eventually improve our knowledge about the atmosphere. Observations of cloud patterns [*Fritz*, 1959] and measurements of the planetary heat budget offer the greatest promise of early results in the form of basic knowledge and practical application. Therefore, the United States program of meteorological measurements from satellites has so far concentrated mainly on these observations. In addition, programs are being considered for eventual measurements of world-wide precipitation by radar and of the world-wide temperature distribution in the stratosphere. In 1960, some of these programs will lead to the acquisition of useful data; others will continue in various stages of development.

Summary of meteorological satellite activity

Clouds—The Vanguard II [*Stroud*, 1958] photocell cloud experiment was launched on February 17, 1959. Although many signals were received, no results have been obtained thus far because of the erratic motion of the satellite.

The Explorer VI 'Paddlewheel' experiment launched on August 7, 1959, produced the first satellite cloud pictures, but these are too crude to be of meteorological value.

The potential value of cloud pictures from high levels was revealed by a 16 mm film obtained on the Atlas rocket flight of August 24, 1959 [*Vachon* and *King*, 1959]. Pictures were taken from altitudes of 200 miles over the Bahama Islands to more than 700 miles above the tropical mid-Atlantic. The following description illustrates the usefulness of this type of data.

Figures 1 and 2 are mosaics assembled [*Hubert* and others, 1960] from a few frames of this film when the rocket was about 400 and about 700 miles high, respectively. They illustrate the wealth of information presented by this new source of meteorological data. Figure 3, from

FIG. 2—Mosaic assembled from photographs taken from an altitude of about 700 miles

the same reference, depicts the trajectory of the missile, the positions at 400 miles and at 700 miles corresponding to the mosiacs. The map in figure 3 also shows the meteorological systems that were identified by analysis of conventional observations, namely, the front extending eastward into the Atlantic from Cape Hatteras, the tropical low pressure belt (labeled 'equatorial trough'), and the 'easterly wave' over Cuba. The latter is the most common synoptic disturbance of the American tropics and accounts for a large part of the rainfall there. These features are also evident on the mosaics. Another outstanding feature in the pictures is the organization of the clouds in 'streets' revealing the large scale circulation in the Atlantic Ocean. Observations on so large a scale have never been possible before.

Heat budget—One of the instruments on the Explorer VII satellite, launched on October 13, 1959, was the heat budget device designed by Professor V. E. Suomi of the University of Wisconsin. Signals from this satellite are now being evaluated. The construction is different from, but the principle of the experiment is similar to, the one described by *Suomi* [1958].

Temperature—Work is also progressing on the design of a spectroscope for satellite use. *Kaplan* [1959] has suggested that the temperature of the atmosphere could be calculated from spectral measurements of the emission of carbon dioxide. To do this for the lower atmosphere will be very difficult, if possible at all, because clouds, and other factors, complicate the interpretation. But it may be possible to determine stratospheric temperatures by this method, and studies to evaluate the possibility are proceeding.

The spectroscope may also serve as a means of observing the temperatures of the Earth's surface or of cloud tops, by spectral observation in the water vapor window.

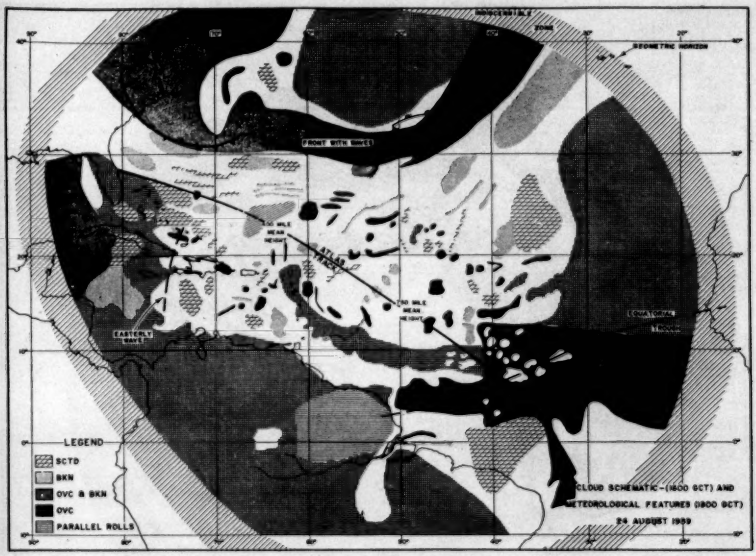

FIG. 3—Trajectory of missile taking photographs of Figures 1 & 2

Radar—The use of radar [*Mook* and *Johnson*, 1959] for the observation of precipitation has been suggested, and work is proceeding to investigate this further.

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United States National Report, 1957-1960
Twelfth General Assembly
International Union of Geodesy and Geophysics

GEOMAGNETISM AND AERONOMY

LEASON H. ADAMS, *Editor*

General Geomagnetism

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The general geomagnetic program of the United States during the past triennium has been carried on by a number of agencies and organizations. The largest single element in the program was, of course, the International Geophysical Year, followed by the International Geophysical Cooperation—1959. The general plan of the United States participation in the IGY is well known and will not be repeated here. The work of the IGC-59 consisted essentially of (a) the operation of the Guam Magnetic Observatory by the Coast and Geodetic Survey as a permanent installation, and the continuation of the normal functioning of 7 permanent observatories—Fredericksburg, Tucson, San Juan, Sitka, College, Barrow, and Honolulu; (b) the continuation, with the support of the National Science Foundation, of Antarctic magnetic observatories at the Byrd Station and at the Pole Station; (c) the continuation of two other Antarctic magnetic observatories, at Wilkes Station and at Hallett Station, through cooperative agreements with Australia and New Zealand, respectively; and (d) the making of magnetic measurements by trail parties on several overland excursions in the Antarctic, carried on by the Arctic Institute of North America and the University of Wisconsin.

Measurements of the vertical component of the magnetic field were made on the traverses at roughly 3 to 5-mile intervals, along with gravity measurements. On some of the traverses magnetic declination and horizontal intensity were also measured. Several airborne tracks were flown in the Antarctic, using a recording proton-precession magnetometer.

A standard Ruska magnetograph has been sent to the Pole Station to replace the Askania Variograph operated heretofore, and the installation is reported to be well under way. Absolute value of total intensity is now being measured at Byrd Station with a portable proton-precession magnetometer for routine baseline control, and a similar instrument will be sent to the Pole Station next year. Standard absolute magnetometers are used for declination and horizontal intensity measurements.

The Honolulu Magnetic Observatory of the Coast and Geodetic Survey is being rebuilt in a new location about 8 km east of the current site, because of industrial encroachment that will cause substantial magnetic disturbance.

The U. S. Navy Hydrographic Office announced its Project MAGNET, a plan for an extensive airborne magnetic survey during the next few years of most of the ocean areas of the world. It will consist essentially of planned around-the-world flight tracks, which will initially be widely spaced to provide a coarse-grained world survey in a short period of time, with each succeeding global mission narrowing the gap until the basic spacing of 200 miles is realized. The basic instrumentation for this project is the Vector Airborne Magnetometer, with various navigation aids to assure the high-

est possible accuracy in determining position and orientation of the aircraft at all times. Two aircraft are now being used: a WV-2 Super Constellation, and an R5D (Douglas DC-4). During the period 1957-59 approximately 130,000 nautical miles of survey track were flown at altitudes of 10,000 to 20,000 feet.

A new edition, for 1960, of Hydrographic Office Chart 1706, isogonic chart of the world, was compiled by the Coast and Geodetic Survey in collaboration with the Hydrographic Office and in consultation with the Astronomer Royal of Great Britain. Also, a 1960 edition of the Isogonic Chart of the United States (including Alaska and Hawaii) was compiled and published by the Coast Survey. Two additional series of magnetic charts for 1960 were compiled by the Survey: a 3-section isogonic chart of Central and South America, showing detail comparable with that on the U. S. isogonic chart, compiled for and published by the U. S. Army Map Service; and an isogonic chart of the Great Lakes area in the United States, showing somewhat greater detail than the U. S. isogonic chart, compiled for and published by the U. S. Lake Survey of the Corps of Engineers.

Numerous magnetic measurements were made from rockets in arctic, equatorial, and antarctic regions, the work being done primarily by teams from the State University of Iowa, from the Naval Research Laboratory, and from the Army Ballistics Laboratory. Two attempts were made by Goddard Space Flight Center of the National Aeronautics and Space Administration to place a magnetic-field satellite into orbit. The first was unsuccessful, but the second (*Vanguard* III) went into orbit on September 18, 1959. Ground monitoring magnetic stations were operated in connection with this flight at points in the United States, British West Indies, Cuba, Equador, Peru, Chile, and Australia. The instrumentation of the satellite functioned properly throughout the 85 days of battery life, and preliminary results bearing on the accuracy of computed fields at altitude, the stability of the Earth's field in space, the Capetown anomaly, and magnetic-storm effects have already been published.

During the past three years the U. S. Geological Survey has flown 150,000 traverse miles while conducting total-field aero-magnetic surveys in the United States, including Alaska. It is estimated that during the same period private companies flew more than a million traverse miles throughout the world. The Geological Survey has continued, as have most private companies, to use the fluxgate or saturable-core magnetometer, although some work has been done with the proton-precession magnetometer. An important development has been the use of high-speed computers in the compilation and preparation of data. New exploration techniques have been developed, and many commercial organizations now conduct airborne magnetic, radiation, and electromagnetic surveys simultaneously. The 'Afmag' instrument has been introduced—a device for measuring the electrical properties of the Earth's crust by employing *natural* random alternating magnetic fields of audio and sub-audio frequencies. Helicopter-borne electromagnetic surveys are being used to some extent to aid in the search for sulfide bodies.

The U. S. National Bureau of Standards remeasured the gyromagnetic ratio of the proton, using a method of free precession. Distilled water supplied the protons. The provisional value, which has been published (*Physical Review Letters*, vol. 1, no. 11; 1958) by Driscoll and Bender, has not been accepted as final. The work was done at the Fredericksburg Magnetic Observatory of the Coast and Geodetic Survey, but it is now being repeated at the National Bureau of Standards, a location closer to the primary voltage standards of the Bureau. Results are not expected to be different by an amount significant in geomagnetic work.

The development of the rubidium-vapor magnetometer, initiated at Fredericksburg, has been carried on by the National Aeronautics and Space Administration in cooperation with a commercial instrument manufacturer, to the point where it is expected to measure accurately and satisfactorily very small magnetic fields—intensities of the order of 5 to 10 gammas or less—and thus it is well suited for use in high-flying satellites or interplanetary measurements.

A team from the University of Chicago organized and completed a survey to locate the cosmic-ray equator, finding that it did not follow the eccentric dipole-field equator. Instead, it seemed to show better corelation with the dip

equator although there were discrepancies. It was thus shown that not only the dipole field but also the large magnetic anomalies are instrumental in determining the cosmic-ray paths.

The Scripps Institution of Oceanography carried on some work in the Pacific Ocean off the coast of the United States during which magnetic measurements were made with total-field magnetometers mounted in a 'fish' towed by cable behind the oceanographic vessel. Further work of this kind is expected to be done in the future.

During the past three years there has been an increasing interest in paleomagnetism, particularly on the possibility of using such measurements to study polar migration and continental drift. The majority of these measurements have been made by the English throughout the British Empire, but several United States investigators have studied the Columbia and Snake River basalt flows. The U. S. Geological Survey, more than a dozen major universities, and several petroleum companies are now equipped to measure remanent magnetization and are actively pursuing studies in the field. Many of these, including the Geological Survey are investigating the effect of stress, mineral composition, and other factors that appear to have an effect on the direction of remanent magnetization. The objective of this work is to develop criteria which can be used to decide which rocks can be used for reliable paleomagnetic studies.

The Bibliography on General Geomagnetism compiled by David G. Knapp that follows is essentially a part of this report. It is intended to include the more important contributions to the literature originating in the United States.

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Geomagnetic and Geoelectric Variations

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During the IGY, the United States operated several geomagnetic observatories in five main regions of both hemispheres: Arctic region and Alaskan network, continental United States network, Pacific region, South American equatorial network, and Antarctic region [*IGY Bulletin*, No. 3, 4, and 17]. Using these data, particularly magnetograms obtained in continental United States network, *Matsushita* [1958, 1960] studied geomagnetic storms, especially sudden commencements, and obtained the following three results. (1) There are three different types of sudden commencement showing a remarkable local time and latitude dependency. (2) The daytime amplitude enhancement of sudden commencement in the horizontal component, which is well known at Huancayo, also occurs at other stations near the dip equator, such as Jarvis Island and Koror. (3) The vertical component of the sudden commencement differs in ways suggesting notable irregularities of the Earth conductivity in the central part of the continental United States. *Akasofu* and *Chapman* [in preparation] thoroughly reviewed previous works on sudden commencements.

Using the IGY data, Matsushita also studied day-to-day change of the location of the daytime center of the solar quiet (Sq) overhead current in the continental United States, and found that the center locates around the latitude of Tucson in summer, and shifts toward lower latitude about 10° in winter. The overhead current is believed due to dynamo effects caused by winds near the 100 km level of the Earth's atmosphere. *Vestine* [1958] investigated these upper air winds from his estimations of day-to-day change of the Sq current-intensity, using *foF*2 data obtained at Huancayo and the solar wave radiation index δw_s from 1938 to 1946. His conclusion was that day-to-day wind change, rather than changes of electric conductivity in the ionospheric *E* region, was mainly responsible for the change of the current intensity. Direct observations of the wind in the upper atmosphere, such as by radars, ionosondes, and released sodium, potassium, and cesium clouds, are important for the study of geomagnetism. However, these are ignored in the present report. Relating to the above mentioned dynamo effects, *Farley* [1959] calculated the electrostatic field in the ionosphere.

One of the most interesting geomagnetic phenomena occurring during the IGY was artificial storms caused by the high-altitude nuclear explosions, Teak and Orange, above Johnston Island on August 1 and 12, 1958, respectively. *Matsushita* [1959ab] and *McNish* [1959] studied geomagnetic variations observed at Apia and United States Pacific stations. McNish concluded that the artificial storms were due to the increase of the electric conductivity in the *D* and *E* region in a wide area centering Johnston Island. Matsushita, on the other hand, suggested from his auroral, geomagnetic and ionospheric

studies that not only the increase of the conductivity but also winds and shock waves due to the explosions were the cause of artificial storms.

Photographs of the Teak event taken from Maui [*Steiger and Matsushita*, 1960] clearly showed the effects of shock waves. Concerning these explosion effects, *Kellogg* and others [1959] mentioned geophysical effects, *Utlaut* [1959] reported ionospheric variations at Maui, *Malville* [1959] discussed artificial auroras, and *Samson* [1960] described effects on radio noise. The other high-altitude explosions (Argus I, II, and III) did not show any remarkable geomagnetic variation in normal magnetograms because of their high explosion altitudes. However, extremely low-frequency signals received after Argus II and III were distinguishable from background electromagnetic effects. The period of the signal was between about ½ and 2 cycles per second, and the amplitude ranged from about 1/25 to 3/2 gamma [*IGY Bulletin*, No. 27, *Newman*, 1959].

Recent observing techniques, rocket, satellite, and balloon measurements of the Earth's upper-atmospheric phenomena, gave valuable information for the study of geomagnetism. Discovery and observation of Van Allen radiation belts, atmospheric drag or magnetic damping effects of satellites, and various balloon observations of the solar corpuscular and electromagnetic radiation during flares and geomagnetic storms are all important for the study of geomagnetic disturbances and storms. However, the present short report cannot cover all of these, but simply mentions the following types of rocket observation. Rocket measurements of ionospheric currents, which are responsible for geomagnetic variations, were carried out by *Heppner* and others [1958] at White Sands, by *Cahill and Van Allen* [1958] and *Cahill* [1959a] near the magnetic equator, and by *Cahill* [1959b] above Greenland. The most interesting result was Cahill's equatorial observation, concluding that the equatorial electrojet consisted of at least two layers of electric current, one layer near an altitude of 100 km and the other 20 to 25 km higher, and also that a return current was flowing north of the electrojet. A theoretical explanation of the double electrojets was attempted by Cahill and *Matsushita* [1959c]. In very high frequency forward scatter experiments in the equatorial region of South America, *Bowles* and *Cohen* [1958, 1959] studied the electrojet, and compared their data with geomagnetic variations and equatorial sporadic-*E*. They found that variations of geomagnetic horizontal intensity correlated well with variations of the radio-field strength. The correlation between geomagnetic horizontal intensity and equatorial sporadic-*E* was also reported by Matsushita. As mentioned in *Odishaw's* [1958] report of IGY activities, S. E. Forbush analyzed IGY geomagnetic data obtained in the South American equatorial network and estimated the width of the electrojet band as about 1000 miles centering within one degree of latitude of Huancayo. Forbush also discussed possible return currents for the electrojet.

Micropulsations of the Earth's magnetic field have been a curiosity ever since Stewart's first observation of them a hundred years ago. Recently several people in the world have started to investigate them intensively. *Campbell* [1959] observed pulsations with periods of 5 to 30 sec in California, and showed interesting morphological results, such as the diurnal behavior of pulsations and their correlations with Kp index. In Alaska he also found a correlation between micropulsations and pulsative auroral intensities. *Maple* [1959] showed that micropulsations at Tucson, which had periods from 2 to 12 sec (mainly 8 sec), were predominant at night, and those with periods from 13 to 32 sec (mainly 20 sec) were predominant in the daylight hours. Night-time pulsations indicated a correlation with Tucson K index. He also attempted to explain sources of the pulsations by a hypothesis of ionospheric intra-layer resonance. Geomagnetic fluctuations in the frequency range of 1 to 50 cycles per second were observed by Maple at a network of stations. *Hawkins* [1958] measured geomagnetic pulses in conjunction with meteor observations by Super Schmidt cameras, and obtained no correlation between the two.

A detailed morphological work of great magnetic storms was reported by *Sugiura* and *Chapman* [1958], using world-wide data for 74 great storms with sudden commencements that occurred in 1902–1945. Comparing their result with their previous similar works for weak and moderate storms, they found that some characteristics of Dst changed with intensity, but the main characteristics of DS were independent

of intensity. *Vestine* [1959a] surveyed current problems of magnetic storms. As for theoretical works of storms, *Dessler* and *Parker* [1959] introduced a hydromagnetic theory, suggesting that the storm is caused by a sudden increase in the intensity of the solar wind. They explained the average characteristics of storms in the following way. The sudden commencement is due to a hydromagnetic wave generated by the impact of the solar plasma on the geomagnetic field, and the initial phase of the storm is due to the increased solar-wind pressure. Trapped protons set up stresses, mainly due to centrifugal force, which account for the main phase of the storm. Also, *Dessler* [1958] and *Francis* and others [1959] attempted to explain the time lag of occurrence of sudden commencement in the world-wide stations, by hydromagnetic propagation velocity. *Warwick* [1959] suggested from magneto-hydrodynamic and ion-cloud theories that such currents will flow in plasma sheets moving along the curved magnetic lines of force as a condition of dynamic balance of centrifugal forces. These currents produce perturbation fields of the size and direction required to explain storm time geomagnetic variations. He also calculated 'horns' in incident ion clouds, and discussed the night-time enhancement of the disturbance daily variation. *Bless* and others [1959] discussed geomagnetic bay disturbances using their auroral observations and the Cheltenham K index. *Nichols* [1959] gave a good summary of auroral ionization and magnetic disturbances. *Nicholson* and *Wulf* [1958] studied disturbances using the K index for six stations. Solar radio, cosmic ray, ionospheric absorption by radio, and Riometer [*Little* and *Leinbach*, 1959] observations in high latitudes are very significant for studies of magnetic disturbances and storms. However, all reports on these observations are ignored here. Many works on correlations between geomagnetic indices and solar or meteorological phenomena are also ignored.

Concerning the distribution of the Earth's magnetic field, *Vestine* and *Sibley* [1959] calculated lines of force of the field at various latitudes and longitudes, using the first eight Gauss coefficients. *Vestine* [1959b] further calculated conjugate points of 55 auroral and whistler stations using the first 48 Gauss coefficients. *Zmuda* [1958] reported a method for analyzing values of the scalar magnetic intensity, and *Millman* [1959] discussed the geometry of the Earth's magnetic field at ionospheric heights.

Hessler and *Wescott* [1959], at College, Alaska, studied rapid fluctuations of the Earth current with ranges larger than 5 mV/Km and periods from 6 to 30 seconds, and obtained a pronounced diurnal variation. *Sugiura* [1958] discussed the rapid fluctuation in terms of a periodically-varying infinite linear current (or turbulent circular current of small radius) in the ionosphere. *Hessler* and *Franzke* [1957] reported on measurements of Earth potential in permafrost and tundra.

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Solar-Terrestrial Relationships

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The great 'cosmic-ray flare' of February 23, 1956 touched off a large number of new solar-terrestrial researches. These have culminated in the discovery, among other things, of terrestrial polar-cap ionospheric absorption effects of great severity apparently originating from high-speed charged particles emitted from the Sun with cosmic-ray energies [*Reid* and *Leinbach*, 1959; *Bailey*, 1959; *Bailey* and *Harrington*, in preparation].

More than 20 instances of abnormal polar-cap absorption have now been observed and from their study have emerged several highly interesting conclusions: (a) solar particles, mostly protons, are accelerated at the times of certain flares to velocities of the order of 10% that of light, and produce substantial ionospheric absorptions effects within a few hours, within the auroral zone; (b) the absorptions sometimes continue with gradually diminishing intensity for as much as five days, with isotropy of proton arrival direction at Earth developing within a few hours after the flare; this implies that the energetic solar protons are 'stored' in the solar system within a few astronomical units of the Sun, presumably in a Sun-generated magnetic-field configuration [*Meyer* and others, 1956; *Lüst* and *Simpson*, 1957]; (c) severe polar-cap absorptions can take place without any auroral emission or of geomagnetic disturbance and are extremely uniform in distribution and decay; (d) if a major magnetic storm and aurora follows the polar-cap absorption, within a day or two, the absorption effect is characteristically extended farther from the polar cap as solar protons are permitted, presumably by field distortions, to reach magnetic latitudes well below the normal cutoff latitudes for such particle rigidities.

The nature of the generation mechanism for the 'solar cosmic rays' is still in doubt, though it appears to be associated with powerful solar radio-noise emission at meter wavelengths, particularly of the Type IV (continuous-emission) character.

Equally significant solar-terrestrial advances have occurred as the result of satellite researches. One such result was the discovery of unexpectedly large fluctuations in the magnitude of the drag on satellites apparently resulting from variations in solar activity as reflected by the 10-cm radio noise and by certain flare-induced geomagnetic storms [Jacchia, 1959].

Even more striking was the discovery of the geomagnetically trapped solar corpuscular radiation [*Van Allen*, 1959], which exhibits large fluctuations, both increases and decreases, with the arrival of the solar corpuscular clouds responsible for geomagnetic storms. Remarkable changes occurred in the outer belts of trapped radiation on several occasions in 1959.

Detailed theories of the origin of geomagnetic storms in solar corpuscular emission are still relatively unsatisfactory. It has been shown empirically, however, that when strong solar radio-noise phenomena at frequencies $\leqq$ 200 Mc/s accompany a solar flare, regardless of its position on the solar disk, the probability of a strong geomagnetic storm within the next three to five days is greatly enhanced [*Dodson* and *Hedeman*, 1958]. Moreover, *Warwick* and *Wood* [1959] found evidence that sudden ionospheric disturbances responsible for shortwave fadeouts appear to occur preferentially when the associated solar flare is elevated above 12,000 km from the solar photosphere.

Solar observations from rockets have produced fruitful results in recent years [*Friedman*, 1959]. R. Tousey and his colleagues at Naval Research Laboratory have obtained an excellent photograph of the solar disk in Lyman α radiation showing the intensification of the disturbed solar regions. At the 1958 solar eclipse, Friedman, Chubb and colleagues showed experimentally, for the first time, that soft x-rays, of the order of 50 A in wavelength,

originate in the solar corona, as theory leads one to expect. They have also detected strong x-ray 'flashes' of radiation to wavelengths below 1 A at times of solar flares. Hinterreger and Rense, in separate experiments, have estimated the intensity of the ionized helium resonance line at 304 A as extremely high, perhaps reaching the order of magnitude of an erg per square centimeter per second, outside the ionosphere. All of these rocket observations, of course, have great ionospheric significance. For example, F. S. Johnson has discussed the interpretation of the *F*-region physics in terms of the rocket observations of Lyman α emission [*Johnson*, 1959].

Much attention has been given to the extension of the solar corona to large distances from the Sun. Chapman, for example, has proposed that thermal conduction in the corona may be a significant source of heat to the ionosphere even at the Earth's distance [*Chapman*, 1957]. This hypothesis has been criticised on grounds that it ignores cooling by radiation from coronal ions [*Warwick*, 1959], and on grounds that the coronal intensity and temperature gradients near the sun are too steep to accord with the conduction model [Pottasch, in press].

Parker [1959] and *Gold* [1959] have examined the extension of the corona into interplanetary space, considering the interaction of the coronal plasma and solar magnetic fields. This work has led to explanations of the storage of solar cosmic rays in the solar system. Parker's model of the 'solar wind' and its interaction with the geomagnetic field has stirred great interest, though objections have been raised that the magnitude of the wind presumed at Earth leads to far too high streaming velocities near the sun, and that the storage of cosmic rays may be accomplished by a field-free hollow around the Sun produced by the static pressure of the sphere of interplanetary gas heated by solar ultraviolet radiation [Newkirk and others, in preparation].

Further work has been done on solar-weather relationships by several groups. More evidence has been found that solar corpuscular emission incident in the auroral zone affects surface weather in a significant number of instances. For example, *Macdonald* and *Roberts* [1960], following up earlier work by these and other authors, have shown that 300-mb troughs in the general circulation were amplified to larger than average values, in three successive winter half-years, when their appearance in the Aleutian Island region was preceded by a strong aurora or sudden-commencement magnetic storm. No satisfactory physical mechanism has been proposed to explain the apparent coupling, though it may be related to Winckler's discovery of significant x-ray production beneath strong auroras at stratospheric levels [*Winckler* and others, 1959].

This brief summary is perforce grossly incomplete. A more detailed summary was recently published by the AGU Committee on Cosmic Terrestrial Relationships [*Vestine*, 1959]. Knowledge of the Sun's variable emissions has grown by leaps and bounds in recent years, and summary reports will soon review these developments. For example, the physics of the solar chromosphere has been comprehensively discussed in a new monograph by *Thomas* and *Athay* [1960]. A briefer general survey of recent developments in solar research will soon appear [*Roberts* and *Zirin*, 1960]. Mention should also be made of the excellent international summaries of the Commission for the Study of Solar-Terrestrial Relationships of the International Council of Scientific Unions [*d'Azambuja*, 1957].

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Ionospheric Research

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General—In the triennium, knowledge of the ionosphere was extended to greater and lower heights. Geographically, through the IGY greater emphasis was placed on investigations in equatorial and polar regions.

Satellite drag data have shown that the densities and temperatures in the high atmosphere are consistently higher than had been thought previously. New atmospheric models have been constructed accordingly [*Schilling* and *Sterne*, 1959; *Kallman*, 1959; *Harris* and *Jastrow*, 1959]. These findings would have made the problem of adequate heat sources even more acute, had not *Rees* and *Rense* [1959] and *Hinteregger* and others [1959] reported rocket observations of solar flux in the extreme ultraviolet which imply several ergs/cm^2 sec (an order of magnitude more than had been expected) of unattenuated flux at these wavelengths above the ionosphere. Also *Chapman* [1957] has indicated the possibility of substantial conduction of heat from the solar corona.

Chamberlain [1958] found good qualitative agreement between the observed night-sky emission of the atomic oxygen line at 6300 A and the emission to be expected (on quasi-theoretical grounds) from the night-time decay of the *F*2 layer.

Routine production of vertical profiles of electron density from *h'-f* records has gotten well under way at Pennsylvania State University's Ionosphere Research Laboratory and the National Bureau of Standards' Central Radio Propagation Laboratory.

Further rocket measurements of electron density profiles made at White Sands, New Mexico, were published [*Seddon* and *Jackson*, 1958; *Pfister* and *Ulwick*, 1958; *Friedman*, 1959].

Experiments with chemical releases by rockets in the upper atmosphere, initiated at White Sands, New Mexico, in 1956, were extended. A series of reports on experiments through September 1958 was initiated by *Marmow* and others [1959]. A new series of experiments,

initiated at White Sands in May 1959, was continued at Eglin Air Force Base, on the Gulf Coast of Florida in September 1959. No published results are yet available for the latter series. The chemicals, including nitric oxide (NO), potassium, sodium, and cesium, have been released at altitudes varying from about 70 to 130 km. Persistent clouds of ionization were formed in some cases, particularly in the case of cesium released in daylight.

A review of ionospheric research from the point of view of extra-terrestrial influences has been made for the period 1957–1959 by the Committee on Cosmic-Terrestrial Relationships of the American Geophysical Union [*Vestine*, 1959].

A comprehensive analysis of the morphology of ionospheric storms was made by *Matsushita* [1959a] using values of *foF*2 during a ten-year period at 38 ionosphere stations between 60°N and 60°S latitude.

The outer ionosphere—Evidence concerning the outer ionosphere (above the height of maximum electron density) was furnished by rockets, satellite beacons, moon-echo experiments, vertical-incidence backscatter, and whistlers and related phenomena.

Bauer and *Daniels* [1958] using measurements of the Faraday rotation of moon echoes found, on the average, about 3.4 times as many electrons above the maximum density as below. Similar measurements were made by *Garriott* [1960] using Sputnik III signals.

Gordon [1958] pointed out the possibility of obtaining echoes by incoherent scatter from electrons. *Bowles* [1958] obtained such echoes and has observed the profile of electron density beyond the height of maximum electron density. This promising new experimental technique is also giving information about the ionic temperature profile.

Wright [1960] has summarized information about the ionosphere above the *F*-region peak (including some unpublished rocket measurements by the Space Technology Laboratory) and has shown that the observations are in reasonable agreement with contemporary theory (taking account of diffusive equilibrium) indicating a Chapman distribution of electron density. The atmospheric scale height obtained is 100 km.

Gallet and *Helliwell* [1959] have proposed that 'whistler-like' noises, which they call 'VLF emissions' are the result of interaction between the medium and streams of ionized particles similar to that which takes place in the traveling-wave tube amplifier. They have shown that through the theory it is possible to deduce information about the ionosphere, exosphere and the particle streams from the characteristics of the VLF emissions.

Helliwell and *Gehrels* [1958] observed propagation of 15.5 kc signals from station NSS at Annapolis, Md. (50°N geomagnetic latitude) from Cape Horn, South America (45°S), via the 'whistler' mode, with large variations in propagation time delay from day to day.

The polar ionosphere—A hitherto unrecognized arctic phenomenon, known as polar cap absorption (also called type III absorption) has been identified and studied by *Bailey* [1959], *Reid* and *Leinbach* [1959]. The phenomenon is relatively rare, being associated with major solar flares, and occurs with remarkable uniformity over the entire polar cap (defined roughly by the lower edge of the auroral zone). The absorption sets in within about 20 min after the onset of the flare, reaches a maximum within a few hours, and then decays slowly during the following few days. After a day or two a sudden-commencement magnetic storm usually occurs accompanied by intense auroral and magnetic activity and the usual sort of auroral-zone radio-wave absorption. These polar cap events are believed to be caused by fast protons from the Sun. Protons of energy 100 to 300 Mev have been observed with balloon-borne detectors [*Anderson* and others, 1959] at atmospheric depths of 10 g cm^{-2}. *Reid* and *Leinbach* [1959] give a table of events from May 1957 to July 1959.

Intense fluxes of soft x-rays have been observed under auroras by balloon-borne detectors [*Winckler* and others, 1959]. They are believed to be bremsstrahlung of 10–100 Kev electrons stopped much higher in the atmosphere. The connection between these x-rays and the intense absorption of radio waves associated with auroras is discussed by *Chapman* and *Little* [1957]. A study of measurements of 30 Mc ionospheric absorption in Alaska using the Riometer (apparatus for recording the intensity of extra-terrestrial radio waves) has been made by *Little* and *Leinbach* [1958].

Measurements of *D*-region electron collision frequencies in the auroral zone were reported by *Kane* [1959]. The measured values were a factor of three lower than some theoretical values.

In a study of sporadic *E* recorded at ionosphere stations in polar regions *Penndorf* and *Coroniti* [1958] distinguished a type of *Es* which is characteristic of the polar cap well inside the auroral ring. They found that its occurrence follows universal time as distinct from auroral zone *Es* which is most prevalent during local night.

Knecht [1959] reports a pronounced universal time variation in *foF*2, a small but significant diurnal variation in *foF*1, but no systematic diurnal variation in *foE* in the ionosphere over the south geographic pole.

For further details of rocket investigations of the polar ionosphere see *National Academy of Sciences* [a].

The equatorial ionosphere—Cahill [1959], by means of a rocket-borne magnetometer, found two layers of electrical current in the equatorial electrojet with current-density maxima at about 105 and 125 km.

Bowles and Cohen (see *Gates*, [1959] for preliminary account) have observed a detailed correlation between the strength of the electrojet (as indicated by magnetic-field variations) and the strength of 50-Mc signals propagated via equatorial sporadic *E*. The same authors have found that equatorial spread *F* echoes arise from ionization irregularities elongated parallel to the Earth's magnetic field in a relatively thin layer at heights varying between about 250 and 600 km.

Irregularities and dynamics of the ionosphere —Booker [1958] has reviewed the use of radio stars to study irregular refraction of radio waves in the ionosphere, and the implications of the results in terms of ionospheric structure and dynamics.

The advent of satellite-borne radio transmitters has offered new opportunities for the study of the transmission properties of the ionosphere. The techniques and some preliminary results have been discussed by *Berning* [1959] (also, see *National Academy of Sciences* [b] for further details of satellite results). The most productive studies of satellite radio transmissions have been those of amplitude (scintillation) and polarization (Faraday rotation). Thus, *Yeh* and *Swenson* [1959] have used 20 Mc *Sputnik III* observations to determine the diurnal variation and geographical extent of the disturbing region responsible for the scintillations, and *Lawrence* and *Little* [1959] have detected large scale (~300 kms) ionospheric irregularities using Faraday rotation measurements. *Kraus* [1958] has observed scattered WWV signals which he attributes to ionospheric irregularities associated with the passage of satellites.

Forward scatter and backscatter experiments have indicated magnetic field-aligned ionization in the *E* region at latitudes far removed from the auroral zone [*Heritage* and others, 1959; *Dyce* and others, 1959]. *Bateman* and others [1959] have reported anomalous low-latitude *F*-region scatter.

In July, 1959, under the joint sponsorship of the International Scientific Radio Union, the International Union of Theoretical and Applied Physics, and the International Union of Geodesy and Geophysics, a symposium on Fluid Mechanics in the Ionosphere was held at Cornell University. The extensive transactions and papers are published in the Journal of Geophysical Research [*Bolgiano*, 1959].

High-altitude nuclear explosions—Two large nuclear bombs were exploded at nominal heights of 60 and 30 km above Johnston Island in the Pacific Ocean in August 1958, producing spectacular and profound results in the ionosphere. *Matsushita* [1959b] and *McNish* [1959] have published accounts of the magnetic effects observed at observatories at Honolulu, Fanning Is., Palmyra Is., Jarvis Is., and Apia. Special effects, including an aurora, were observed at Apia because of its proximity to the magnetic conjugate-point of the explosions. No effects at the orbit of United States satellite *Explorer IV* (launched July 26, 1958) were reported; but later in August three smaller nuclear bombs were exploded at nominal heights of 480 km in the South Atlantic for the purpose of injecting high-energy electrons into the Earth's magnetic field in the long mean free-path region. These electrons were detected by *Explorer IV*. They also produced aurora and other effects in the ionosphere at the conjugate point near the Azores. Ionospheric effects are described by *Newman* [1959] and *Peterson* [1959].

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Auroral Spectroscopy

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Air Force Cambridge Research Center—At AFCRC preflight tests of a rocket-borne scanning ultraviolet spectrometer have been completed. This is to be flown through an aurora at Ft. Churchill, Canada, in March 1960. Additional fixed wavelengths will obtain data on vertical distribution of auroral emissions.

Excellent laboratory work is continuing at AFCRC, including research on molecular nitrogen spectra by Oldenburg, Tanaka, and Mulliken (latter at University of Chicago) and the production of light by proton and neutral hydrogen atom impacts at 30 Kev. by Oldenburg and Sheridan.

Dubs and Sen have been working on the thermal electron attachment coefficient of oxygen molecules and they presented their results at the Fourth International Conference on Ionization Phenomena in Gases at Uppsala, Sweden (Aug. 1959).

Markham has made a preliminary flight along the auroral zone from Iceland westward, photographing the overhead aurora. This flight was made at very high altitude and at a speed equal to the Earth's rotational velocity at flight latitude. These data are being analyzed.

The U. S. Antarctic spectrographic program was instrumented and directed by AFCRC where the data will be finally analyzed. Extensive university auroral research programs are supported by the Ionospheric Physics Laboratory of AFCRC in the United States, Canada, New Zealand, and Europe.

Yerkes Observatory—A very extensive research program in auroral spectroscopy, auroral processes and morphology has been under the leadership of Chamberlain over the last few years. A multiplicity of high- and low-dispersion spectrographs and spectrometers have followed the development of many auroras during the past three years including the IGY. Parallactic spectrography was carried out during the IGY with a satellite station at Shingleton, Michigan. Photometry of various forms was accomplished by *Omholt* [1957]. Special observations are maintained of auroral related parameters such as geomagnetic variations. *Wallace* and *Chamberlain* [1960] in particular, have contributed

generously to the scientific literature during the triennium.

University of California at Los Angeles—Kaplan and Schade are continuing investigations on the O I 5577 line in afterglows in the near ultraviolet region. Research on the forbidden NI lines and the second positive bands of N_2 will be continued throughout the spectral range 2500 to 11,000 A.

Cornell University—Gartlein is continuing operation of three spectrographs on a nightly basis and on bright or unusual displays extends this number to six. Several of these have been in operation since 1940. An all-sky camera is also in nightly operation.

Gartlein and *Sprague* [1957], using auroral spectrograms taken at Ithaca, New York have calculated that the penetration of protons in the atmosphere appears possible to the 110-km level. They also obtained the intensity of H_α by direct comparison with 5577 OI in the night sky and by two other methods. They arrived at a figure for H alpha flux of about 10^{-4} erg per cm^2 column per steradian per second.

Harvard University—Carlton [1957] reached interesting conclusions that the 1st neg and Meinel systems of N_2 + are excited thru charge exchange, that the 1st pos system of N_2 is excited, not by proton impact, but by the impact of fast neutral atoms, that allowed NI lines are excited by a single process involving dissociation and excitation, and that the Balmer lines result from charge capture directly into an excited state.

National Bureau of Standards and University of Colorado—M. H. Rees [1959a b], utilizing photometric data obtained with a Roach-type photometer located at Fritz Peak, Colorado, studied the absolute intensities of the ionized molecular N_2 emission and the OI green line of the low-latitude auroras March 1–2, 1957. He also determined the absolute emission intensity of the IN.G − 3914 band of N_2 + and computed the ion density of N_2 + as a function of height from the emission rate per unit volume.

University of Alaska—Romick and *Elvey* [1958] pointed out that the lack of intensity of the Hβ line of hydrogen preceded that of the 4709 line of N_2 + by one to four hours at the magnetic zenith. *Clark* and *Romick* [1959] developed a meridian spectrograph having a resolution of 25A. This automatic grating instrument was designed to provide greater sensitivity than the IGY patrol spectrograph at H alpha. *Clark* and *Belon* [1959] made extensive investigations of the aurora on February 10 and 11, 1958. Relative enhancement of the various bands was studied. A great abundance of hydrogen was observed entering the earth's atmosphere at velocities exceeding 800 km/sec. Similarly, these measurements lend support to charge exchange processes. Utilizing a Huet flint prism spectrograph having a speed of F/0.7 with an 11° field of view, *Romick* [in press] has in the process of preparation a catalog of time-resolved auroral spectra, College 1958–1959. It will be printed at the Geophysical Institute of College, Alaska.

Murcray [1957] observing from College, Alaska, reported a possible enhancement of ozone in the infrared directly under an active aurora. The enhancement may be due to either an increase in quantity or an increase in temperature or both.

Colgate and Clarkson—Berkey of Colgate University and Moore of Clarkson Institute of Technology are initiating a combined spectroscopic and parallactic photographic study of radiation versus height of auroral arcs. The spectrograph has a speed of f/1.6 and sufficient resolution to separate the Na doublet.

General—Several laboratories have been conducting laboratory research on atomic and molecular processes closely related to auroral emissions. These include Lockheed, General Atomics, Convair, Jet Propulsion Laboratory of the California Institute of Technology, the National Bureau of Standards at Washington and Boulder, Stanford Research Institute, the University of Arkansas, Oregon State College, New York University, Westinghouse, and the University of Pittsburgh. The Naval Ordnance Test Station at China Lake and the Naval Research Laboratory have both conducted auroral spectrophotometry.

Spectral studies of the atmosphere of Venus have been conducted at the High Altitude Observatory of the University of Colorado. Some bands have been tentatively identified but their auroral origin has not been established.

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Auroral and Related Airglow Work at Yerkes Observatory

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Auroral observations—Wallace and *Chamberlain* [1959] have found that the 1–1 atmospheric band of O_2 in the aurora shows a much higher rotational temperature than the 0–1 band. This effect has been interpreted as a consequence of the excitation mechanism of energy transfer from the upper term of the [O I] red lines, followed by vibrational de-activation. *Chamberlain* and *Thorson* [1960] have examined the visual records of auroral occurrences kept at the observatory over a 55-year period to obtain the nightly variation of occurrences. There appears to be a maximum probability in the neighborhood of local magnetic midnight, as at most stations closer to the auroral zone.

Roesler and others [1958] have discussed the interpretation of rotational temperatures of the first negative bands in the auroral spectrum, on the basis of new measurements of the temperature in laboratory sources excited by proton impact. In the range between 10 and 30 kev there is little difference between the gas temperatures and the apparent (rotational) temperatures obtained by proton excitation.

Wallace [1960a] has obtained an excellent spectrogram of the aurora in the 3700–4400A region at a dispersion of 23A/mm. *Chamberlain* [1960a] has made some estimates of the maximum polarization to be expected from λ6300 in the aurora.

Auroral theory—Chamberlain [1957, 1958, 1960b] has studied the hydrogen profiles at the magnetic zenith and at the magnetic horizon to obtain information on the velocities and the angular dispersion of the incident particles. It appears that the profiles cannot be consistently explained with mono-energetic particles; rather a large energy spectrum in the protons seems to be indicated. In line with understanding the nature of auroral particles in space, *Brandt* and *Chamberlain* [1959] and *Chamberlain* [1960] have undertaken a theoretical program on the interplanetary gas. Recent observations of Lyman α in the spectrum of the night sky have been interpreted in terms of the neutral hydrogen density in the interplanetary gas. The work has been extended to make a theoretical prediction of the density and temperature of the ionized gas near the Earth on the basis of evaporation from the solar corona. Further work in this area is dealing with the calculation of the recombination and diffusion of neutral hydrogen, so as to compute the ratio of neutral to ionized particles.

Airglow observations—Wallace [1960b] has been investigating rotational temperatures in the OH bands on a systematic basis through the year. He finds that some previous determinations of temperature have been systematically in error because of approximations generally used in the analyses. *Chamberlain* [1959a] has obtained a spectrum with fairly high dispersion of the blue region of the airglow. The spectrum may contain a new system of weak bands arising from O_2. *Chamberlain* and *Smith* [1959] have made estimates of the excitation rates and intensities of OH bands in the airglow from available transition probabilities and the various published measurements of the absolute intensities of some bands.

Airglow theory—Brandt [1959b] has examined a fluorescent mechanism from Lyman β in the solar spectrum acting on atomic oxygen in the upper atmosphere. He makes a theoretical prediction of dayglow and twilight intensities in the infrared oxygen lines in some far-ultraviolet emissions.

A theoretical program on the resonance scattering by atmospheric sodium has been carried out in collaboration with Hunten [1956, 1960; *Chamberlain*, 1956a; *Chamberlain* and *Negaard*, 1956; *Chamberlain* and others, 1958; *Brandt* and *Chamberlain*, 1958; *Brandt*, 1958; *Rundle* and others, 1960] at the University of Saskatchewan. These papers have discussed the

transfer of radiation in the sodium layer and have related the intensity of the sodium D lines at twilight and daytime to the sodium abundance.

The excitation of the oxygen red lines in the airglow has been discussed on the basis of the mechanism of dissociative recombination and ultraviolet dissociation of O_2 [*Chamberlain*, 1958b, 1959b; *Seaton*, 1958; *Brandt*, 1959a]. *Chamberlain* and *Sagan* [1960] have discussed the production of N_2^+ in the upper atmosphere by particle bombardment and helium emission lines in the solar corona and have related the N_2^+ densities to the twilight and day airglow.

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Airglow Research

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Observing stations—During the triennium there have been four active airglow ground stations in the continental United States. In addition work has been directly sponsored at three other stations in the western hemisphere.

The ground observing program—In general two types of sky coverage have been employed: (1) scanning of the entire sky, (2) observation in a fixed direction as, for example, the zenith.

The emissions studied have included [O I] 5577, [O I] 6300, Na–D (5893) and OH.

Two types of instrument have been employed: (1) photometers with Dunn-Manring birefringent filters, (2) photometric set-ups using a 'control' photometer for subtracting out the astronomical contamination.

Absolute calibrations have been by star observations. An intercalibration on a world-wide basis was made during the IGY. The internationally accepted unit of intensity is the 'rayleigh' which is equal to $4\pi B$ where B is the observed flux in 10^6 quanta/cm^2 • second • steradian.

Some results obtained from ground observations—It was reported that 5577 A airglow exists in the form of cells about 2500 km in diameter, moving with speeds of about 100 m/second and having rotational periods of about 5 hours [*Roach* and others, 1958bc].

The statistical distribution of 5577 intensities in the sub-auroral zone indicates that the distribution of intensities is uni-modal with no discontinuity between the invisible and the visible [*Roach* and others, 1959a]. The distribution at Thule near the geomagnetic pole is similar but the intensities are approximately double those in the sub-auroral regions [*Roach* and others, 1959b]. A controversial interpretation is that the 5577 airglow and the 5577 aurora have a common type of excitation.

A bright aurora on February 10–11, 1958, was observed as far south as Tonanzintla [*Manring* and *Pettit*, 1959]. On occasion intense (but invisible because of their color) arcs in the radiation [O I] 6300 have been observed in the sub-auroral zone [*Roach* and *Marovich*, 1959, 1960]. The arcs occur during times of general auroral activity. They are detached (geographically) from the visible aurora. Their time variations of intensity are independent of the visible aurora.

Evidence has been presented that the 5577 airglow emission is correlated with ionospheric activity in the 100-km region [*McCaulley* and *Hough*, 1959].

Evidence has been presented that the 5577 airglow emission is correlated with geomagnetic activity [*McCaulley* and others, 1960; *Roach*, 1960].

Rocket observations—Definitive height de-

TABLE 1—*Airglow stations during 1957–1960*

	Station	Geographic Latitude	Geographic Longitude	Geomagnetic Latitude	Dates of observing
		° ′	° ′	°	
1	Cactus Peak	36 05 N	117 49 W	43	1959–1960
2	Sacramento Peak	32 47 N	105 48 W	42	1957–1960
3	Fritz Peak	39 54 N	105 29 W	49	1957–1960
4	Rapid City	44 35 N	103 19 W	53	1957–1959
5	Thule, Greenland	76 33 N	68 50 W	88	1958–1959
6	Tonanzintla, Mexico	19 02 N	98 02 W	29	1958–1960
7	Huancayo, Peru	12 03 S	75 20 W	−1	1958–1960

terminations have been made for the emissions 5577 (100 km) and 5893 (85 km) from a series of measurements with photometers carried aloft by rockets [*Heppner* and *Meredith*, 1957; *Tousey*, 1958].

Several rockets have been equipped with atomic sodium generators. When the sodium is ejected the sodium-D lines appear. Of special interest has been the determination of wind speeds at a number of altitudes from the movements of the persistent sodium clouds [*Manring* and *Bedinger*, 1958; *Bedinger* and others, 1958; *Manring* and others, 1959].

International Geophysical Year—The American stations made systematic observations during both the IGY and the IGC. The results will be included in an international airglow book.

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Chemistry of the Outer Atmosphere*

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The physical and chemical description of the outer atmosphere (the ionospheric region and above), as it was known in 1957, was set forth by *Miller* [1957]. His description of the atmosphere is an appropriate background against which to view the developments of the past three years in outer atmospheric chemistry. In studying the question of atmospheric composition, one cannot consider the effects of purely chemical processes independently of the diffusive transport which occurs in the atmosphere above about 100 km. Miller assumed that diffusive equilibrium prevailed above 180 km and considered mixing to be effective up to 180 km in controlling the relative total concentrations of oxygen and nitrogen, with photochemical processes responsible for dissociating the oxygen in the vicinity of 100 km.

It is now rather generally accepted that diffusive equilibrium prevails down to about 100 or 120 km. This opinion is based upon mass spectrometric measurements made in rocket flights at Churchill and showing diffusive separation between argon and nitrogen commencing between 100 and 120 km [*Meadows* and *Townsend*, 1958, 1960].

The O_2 concentration and the total atmospheric density as functions of altitude from 100 to 120 km have been measured [*Chubb* and others, 1958; *Byram* and others, 1955]. These measurements give an indication only of the relative proportion of O_2 in the atmosphere. *Nicolet* [1959] has pointed out that the occurrence of oxygen dissociation in a region where diffusive transport is important makes it impossible to deduce either the degree of dissociation or the relative concentrations of atomic oxygen and molecular nitrogen from the measurements of molecular oxygen and atmospheric density. Nicolet indicates that at 100 km the ratio of the concentration of O to that of N_2 should lie between 0.1 and 2.0. Thus, in addition to the direct measurements of O_2, measurements of O, N_2, and N are needed in order to clarify the question of the chemical composition of the outer atmosphere. The oxygen dissociation which occurs near 100 km is due principally to the absorption of solar ultraviolet radiation in the wavelength region 1350 to 1800A, which results in direct photodissociation. The percentage dissociation is not at all well established, as can be seen from Nicolet's arguments presented above.

Nicolet and *Mange* [1954] noted that nitrogen dissociation would proceed very slowly as there is very little solar energy in the wavelength region shorter than about 800 A which is required to dissociate nitrogen by photoionization followed by dissociative recombination. On that account, it was generally accepted that nitrogen would be only slightly dissociated through most of the ionosphere. Miller differed from the prevailing opinion at the time in showing a considerable degree of nitrogen dissociation, although he had no particularly firm physical basis for his position. *Krassovsky* [1957] and *Hertzberg* [1958] have independently drawn attention to the ion atom interchange reaction

$$O^+ + N_2 \rightarrow NO^+ + N,$$

as an important source of atomic nitrogen. Hertzberg estimates the reaction to be two or three decades more important in releasing atomic nitrogen than is the direct photodissociation of molecular nitrogen followed by recombination. This has had the effect of re-opening the nitrogen dissociation problem and has essentially questioned the validity of the assumption which was the basis for Nicolet's and Mange's earlier deduction that nitrogen should be very little dissociated in the ionosphere. In addition, in 1959, Nicolet suggested another ion atom interchange reaction,

$$N_2^+ + O \rightarrow NO^+ + N,$$

* See Chemistry of the Atmosphere under Meteorology and Atmospheric Physics, p. 186.

which may contribute to the dissociation of nitrogen, but, at the same time, he suggested that the atomic nitrogen is rapidly consumed in the reactions

$$N + O_2 \rightarrow NO + O$$

$$NO + N \rightarrow N_2 + O$$

Thus, Nicolet has put forth a powerful new argument leading to the same conclusion arrived at earlier on the basis of less sound arguments that nitrogen dissociation is slight in the ionosphere, at least up to the $F2$ peak. However, the issue of nitrogen dissociation is not resolved and further measurements will be required. As with oxygen, the complication introduced by diffusion makes it necessary that both N and N_2 be measured in order to determine the degree of dissociation; in addition; in addition, O and O_2 must be measured before the chemistry of nitrogen dissociation can be studied in detail.

Ethylene was released from a rocket at night in the atmosphere above 100 km, and a visible glow was noted [*Zelikoff* and others, 1958]. Near 120 km, the glow was bluish, and this was interpreted as indicating the presence of atomic nitrogen. Near 140 km, the glow was reddish, presumably due to the presence of atomic oxygen. The quantitative interpretation of these experiments appears to be difficult.

The uncertainty with regard to molecular constituents tends to disappear at high levels due to the effect of diffusive separation. At the base of the exosphere, which occurs near an altitude of 550 km, the effects of diffusive separation at lower levels is to reduce the molecular constituents to a small fraction of the whole. The uncertainty at 550 km is the relative concentration of O and N. If nitrogen dissociates at fairly low altitudes, say below 200 km, atomic nitrogen will also surely be more prevalent than atomic oxygen at the base of the exosphere. On the other hand, if nitrogen dissociation is slight, then the atmosphere at the base of the exosphere must consist mainly of atomic oxygen.

An interesting and important minor constituent of the atmosphere at ionospheric levels is atomic hydrogen. This is released by photochemical decomposition of water vapor or methane near 80 km [*Bates* and *Nicolet*, 1950]. The atomic hydrogen diffuses up through the atmosphere and escapes at the rate 10^8 atoms cm^{-2} sec^{-1}. *Johnson* and *Fish* [1960] have identified the escaping corona of hydrogen as responsible for the scattering to the night-time side of the Earth of solar Lyman α radiation [*Kupperian* and others, 1958] and have provided a quantitative description of the hydrogen corona. The temperature of the hydrogen is the same as that of the atmosphere near the base of the exosphere, or 1250°K, according to the orbital decay for 1958β 2 presented by *Harris* and *Jastrow* [1959]. The data of *Johnson* [1960ab] has suggested that the charge exchange reaction

$$O^+ + H \longleftrightarrow P + O$$

is responsible for the release of thermal (1250°K) protons which form the protonosphere, an extension of the ionosphere to very high levels which accounts for the propagation of radio whistlers. This reaction is a case of accidental reasonance; the reaction proceeding to the right is weakly exothermic (0.02 ev) by an amount which is much smaller than the average thermal energy near the base of the exosphere (~0.1 ev). The cross section for the reaction has been measured by Stebbings (private communication, 1960) and is large enough to explain quantitatively the proton (and electron) density required to propagate the radio whistlers.

The atomic hydrogen surrounding the earth takes part in another reaction of geophysical importance. The main-phase decrease of geomagnetic storms is thought to be due to solar protons with approximately 10 Kev energy becoming trapped in the Earth's magnetic field and distending it. [*Singer*, 1957; *Dessler* and *Parker*, 1959]. The energetic protons exchange charge with the thermal (1250°K) hydrogen atoms in a reaction

$$P_h + H_t \rightarrow H_h + P_t$$

where the subscripts h and t indicate high and thermal energies respectively. After the charge exchange, the high-energy hydrogen atom is lost to space and the thermal proton does not exert the distending force on the magnetic field that the high-energy proton did. This reaction proceeds with about a one-day time constant, according to the cross section for the reaction measured by *Fite* and others [1958], and prop-

erly explains the time constant for the decay of the main phase of geomagnetic storms [*Dessler* and *Parker*, 1959].

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Radiation Belts of the Earth

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Introduction—One of the interesting geophysical discoveries of recent years was that made with the early U. S. satellites *Explorer I* (Satellite 1958α) and *Explorer III* (Satellite 1958γ). It was found that an immense region of space around the Earth is occupied by a high intensity of charged particles—protons and electrons—temporarily 'trapped' in the geomagnetic field. This early work was first reported by Van Allen, Ludwig, Ray, and McIlwain of the State University of Iowa on May 1, 1958 at a joint meeting of the National Academy of Sciences and the American Physical Society in Washington, D. C. Detailed study of this radiation has been carried forward with equipment in satellites and space-probes by the Iowa group, by a group of IGY workers in the Soviet Union (Vernov, Chudakov, Krassovsky, Galperin, and others), and, more recently, by others. Important additional information at relatively low altitudes has been obtained by brief rocket flights by other workers. And as this article is being written there is an increasing tempo of observational and interpretative work underway in many laboratories.

Although knowledge of the trapped radia-

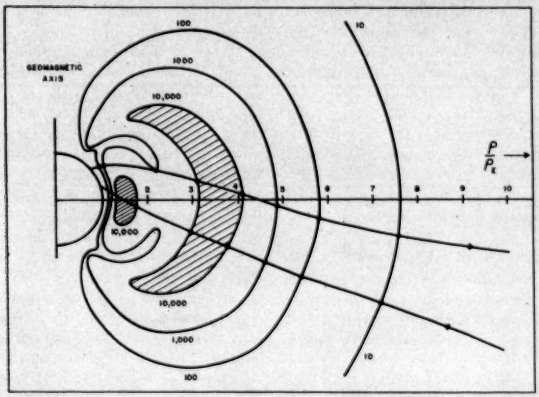

FIG. 1—Typical intensity structure of the radiation belts around the Earth.

tion is still incomplete, substantial progress has been made in observing and understanding this newly discovered phenomenon.

The subject has also been advanced by the Argus experiments of August-September 1958. These experiments comprised the artificial injection of beta-decay electrons from the fission fragments of high altitude detonations of small-yield atomic devices and the subsequent observation by *Explorer* IV (Satellite 1958ϵ), by sounding rockets, and by other techniques of the geophysical effects produced. The Argus experiments were originally proposed by Christofilos.

Intensity structure of the trapped radiation—Figure 1 gives an overall view of the intensity structure of the two principal radiation zones (or belts) around the Earth as derived from the Geiger-tube observations of *Explorers I, III, IV,* and *Pioneer III*. Generally confirmatory results have been obtained by the Soviets with radiation instrumentation on *Sputnik III* and the First Soviet Cosmic Rocket. An immense amount of more detailed information at lower altitudes is available in the full gamut of *Explorer IV* observations with a variety of detectors. Figure 1 shows a geomagnetic-meridian section of a three-dimensional figure of revolution around the geomagnetic axis. Contours of constant intensity are labeled 10, 100, 1000, and 10,000. These numbers are true counting rates (counts/second) of an Anton Type 302 Geiger tube carried by *Explorer IV* and *Pioneer III*. Throughout the cross-hatched regions the rate exceeded 10,000 counts/second, having a maximum value of about 25,000. The two distinct, high-intensity regions are called inner and outer zones respectively and the low intensity region between them, the slot. The linear scale of the diagram is in units of the radius of the Earth, 6371 km. Outbound and inbound legs of the trajectory of *Pioneer III* are shown by the slanting, undulating lines.

The intensity structure is a function of detector characteristics, of course. Also the structure of the outer zone exhibits marked temporal fluctuations. Thus, it should be understood that this diagram represents only a sample situation as determined with a particular detector. Nonetheless the broad nature of the diagram seems to have a general significance.

More recent data, from *Pioneer IV* on March 3, 4, 5, and 6, 1959, again confirm the general structure of the region of trapped radiation but show a very great enhancement of intensity and a considerable extension of the radial limits of the outer zone, following a probable M-region event on the Sun on February 25, 1959. In addition, these data provide information on the

absorptivity of the radiation in both inner and outer zones and give a new determination of the cosmic-ray intensity in interplanetary space.

Nature of the trapped radiation—The trapped radiation consists of protons and electrons constrained to bound orbits by the geomagnetic field in the manner visualized in classical theoretical studies by Poincare, Stoermer, and Alfven.

The radiation in the inner zone is quite different in composition than that in the outer zone.

In the heart of the inner zone at an altitude of about 3600 km on the geomagnetic equator the approximate composition is as follows: (a) electrons of energy greater than 40 kev; maximum of unidirectional intensity $\sim 2 \times 10^6$/cm^2 sec steradian; (b) electrons of energy greater than 600 kev; maximum of unidirectional intensity $\sim 1 \times 10^7$/cm^2 sec steradian; and (c) protons of energy greater than 40 Mev; omnidirectional intensity $\sim 2 \times 10^4$/cm^2 sec. The inner zone is observed to be relatively free of temporal fluctuations.

The outer zone, as mentioned above, undergoes marked temporal fluctuations. It appears that *Pioneer IV* passed through the outer zone during a period of exceptional enhancement (March 3, 1959). The composition of the radiation in the heart of the outer zone (altitude about 20,000 km on the geomagnetic equator) on that date was approximately as follows: (a) electrons of energy greater than 40 kev; omnidirectional intensity $\sim 1 \times 10^{11}$/cm^2 sec; (b) electrons of energy greater than 200 kev; omnidirectional intensity less than 1×10^9/cm^2 sec; (c) protons of energy greater than 60 Mev; omnidirectional intensity less than 1×10^6/cm^2 sec; (d) protons of energy less than 30 Mev; no significant information.

Origin of the trapped radiation—It now appears that the protons and electrons in the inner zone are the products of the radioactive decay of neutrons moving outwards from the top of the atmosphere, these neutrons being released from cosmic-ray-induced nuclear disintegrations in the atmosphere.

The outer zone almost certainly owes its existence to ionized solar gas which is ejected from the Sun, travels to the Earth and is injected into the geomagnetic field. Presumably the outer zone contains very large densities of protons and electrons whose energies lie below the detection limits of instruments used thus far. The site and mechanism of acceleration of outer zone particles to the energies observed are not yet known. Present evidence, though not conclusive, favors 'local acceleration' within the outer reaches of the fluctuating geomagnetic field. It might conceivably be that the geomagnetic fluctuations induced by the arrival of solar plasma accelerate electrons and ions already present in the Earth's ionosphere (Krassovsky).

Trapped particles eventually 'leak out' of the radiation zones by virtue of collisional energy loss and scattering in the thin outer atmosphere and by virtue of magnetic scattering in the fluctuating geomagnetic field. Representative values of the mean trapping time for protons and electrons of various energies lie in the range 10^6 to 10^9 sec. The observed intensities at any one time are thus to be understood as the quasi-equilibrium values in a dynamic physical situation.

Geophysical significance—It is probable that the outer radiation zone, in particular, plays a central role in many geophysical phenomena: auroras, geomagnetic storms, airglow, and atmospheric heating. Study of detailed mechanisms is being actively pursued by many investigators. The discovery of the terrestrial ring current by Dolginov and Pushkov in the inner portion of the outer radiation zone is of special note.

A number of references bearing on this work are found in a paper entitled *The Geomagnetically Trapped Corpuscular Radiation* by the author of this report published in the *Journal of Geophysical Research*, vol. 64, pp. 1683–1689, 1959.

Cosmic Radiation Research in the United States

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The remarkable progress in cosmic-radiation research during the past three years has been stimulated by a number of factors. On the one hand, its close relationship to astrophysics and some aspects of geophysics has become more widely recognized and has led to a concentrated experimental effort especially during the International Geophysical Year. On the other hand, new and improved techniques have recently become available. Many and extensive experiments are carried out near the top of the atmosphere using modern balloon techniques and artificial Earth satellites, and space probes now permit measurements outside the Earth's atmosphere and its magnetic field.

Cosmic-ray research today divides into two parts. One group of investigations is concerned with the study of interactions between nuclear particles at high energy using cosmic radiation as a source of these particles. We shall not report on this type of work here. The other group of investigations centers around the question of the origin of cosmic radiation, its relationship to astrophysical phenomena such as solar activity and its interaction with the interplanetary medium.

In this brief review we shall try to summarize the major advances which have been made in this field of cosmic-ray research in the United States. We shall not attempt a critical interpretation of the result.

Primary Energy Spectrum and Mass Spectrum

Measurements of the primary cosmic radiation cover work on the proton component as well as heavier nuclei over a wide range of energies. The energy spectrum up to the highest energy so far observed (10^{20} ev) was investigated by the Massachusetts Institute of Technology group [*Clark* and others, 1957; *Clark*, 1957] in a series of air-shower experiments. These experiments are of astrophysical importance in order to decide what particle rigidity can be confined within the galaxy and its magnetic fields. A detailed search for an anisotropy in the high energy primary radiation has been made by these authors with a negative result. This poses stringent requirements on the distribution and strength of the galactic magnetic fields.

The low-energy portion of the primary cosmic-ray spectrum has been studied experimentally as well as theoretically. Part of this work was stimulated by the discovery that the total cosmic-ray intensity as well as the energy spectrum undergo pronounced changes which are correlated with the 11-year activity cycle of the Sun. We shall report these investigations which are concerned with the primary proton, α-particle and heavy particle components in the section entitled *The modulation of galactic cosmic radiation*.

The old question of the presence or absence of lithium, beryllium, and boron nuclei in the primary cosmic radiation has been reinvestigated by *Freier, Ney,* and *Waddington* [1959a]. An emulsion stack was exposed under 3.8 gm/cm^2 of residual atmosphere over Texas and yielded a total primary flux of the light elements of 1.9 ± 0.3 particles/cm^2 sterad. The presence of the light elements in the primary radiation seems to be established by these measurements.

Acceleration of High Energy Particles by the Sun

It has been known for a number of years that the Sun occasionally produces particles of cosmic-ray energy in association with a chromospheric eruption or solar flare. More recently it became clear that, at least in the years of enhanced solar activity, solar particle acceleration is a rather frequently occurring process. While some large solar flare events produced a particle energy spectrum that reached up to 15 or 25 Bev [*Meyer* and others, 1956], the more frequent and smaller solar bursts show maximum

proton energies of the order of 200 to 400 Mev. The arrival of such low-energy protons at the top of the atmosphere was first observed by *Anderson* [1957, 1958] in 1957 and was subsequently found on various occasions in 1958 and 1959 [*Freier, Ney,* and *Winckler,* 1959b; *Anderson* and others, 1959; *Ney* and others, 1959; *Brown* and *D'Arcy,* 1959] (Fenton and Simpson, to be published) by balloon observation. Most of the characteristics of these small solar-flare effects are similar to the larger cosmic-ray bursts. The differential rigidity spectrum of the solar particles can be well described by a power law $N(R) \sim R^{-\gamma}$ with an exponent γ between 4 and 6 [*Freier, Ney* and *Winckler,* 1959b] where R is the particle rigidity pc/Ze. Also the typical long persistence and slow decline of the radiation intensity after the end of the optical flare is observed in those events. One, therefore, has to invoke storage for the solar-produced particles as was required to explain the time dependence of the particle intensity after the large particle outbursts. Several models have been proposed to explain the particle storage [*Meyer* and others, 1956; *Cocconi* and others, 1958]. Recent measurements by instruments on board *Pioneer V* show (Fan, Meyer, and Simpson, to be published) that this storage mechanism is probably not located in the vicinity of the Sun and certainly not in the vicinity of the Earth. This conclusion was reached after observation of a solar-flare particle increase on April 1, 1960, at a distance greater than 5×10^6 km from the Earth. The observed prompt arrival of solar particles at the detector makes it unlikely that efficient storage takes place close to the Sun and the slow decay of the flux after the initial burst at great distances from the Earth rules out the possibility of storage near the Earth. Several observations of solar flare cosmic ray particles have been made on satellites [*Rothwell* and *McIlwain,* 1959; *Fan* and others, 1960b].

Frequently a solar flare is followed within one to two days by a geomagnetic storm and a sharp cosmic-ray intensity decrease (Forbush decrease) at the Earth. These phenomena are interpreted as being caused by the enhanced emission of solar gas in connection with the flare event, which will reach the vicinity of the Earth in a day or two after its ejection by the Sun. On two occasions it was noted that after the Forbush decrease low-energy solar particles may reach the earth at geomagnetic latitudes which are normally forbidden by the Störmer cutoff [*Freier, Ney,* and *Winckler,* 1959b] (Fenton and Simpson to be published). The detailed mechanism responsible for the breakdown of the geomagnetic cutoff has not yet been established.

An efficient method for the detection of the arrival of nonrelativistic protons at the Earth which are emitted in flare processes on the Sun has been developed by *Reid* and *Leinbach* [1959ab]. These authors study the cosmic-radio noise absorption in the polar region which is produced by the enhanced electron density in the lower ionosphere as a consequence of the impact of ionizing particles. Between 1957 and 1959 more than 20 events could be found where radio-noise absorption associated with the arrival of solar particles followed a solar flare.

In recent experiments the Minnesota group observed the emission of α-particles in solar flare events and obtained a measurement of the energy spectrum (Ney and others, unpublished).

During several measurements which took place at times of no flare event the α-particle flux has been found to vary in a different manner than the proton flux [*Meyer,* 1959; *Freier, Ney,* and *Winckler,* 1959a]. This evidence may point to solar emission of α-particles not directly connected with the flare effect.

The Modulation of Galactic Cosmic Radiation

The two modulation phenomena that were most intensively studied in the past three years are the 11-year variation and the sharp Forbush decreases of cosmic-ray intensity. Both these processes are solar induced, the one being closely correlated with the general 11-year activity cycle of the Sun, the other with discrete, outstanding phenomena taking place on the visible side of the solar surface. Extensive networks of neutron monitor stations have been in existence throughout and after the IGY and have significantly contributed to the interpretation of these effects [*Simpson,* 1957, 1959; *Lockwood,* 1960ab].

The 11-year variation—An inverse correlation between the intensity of the primary cosmic radiation and solar activity was first reported by *Forbush* [1954]. Experiments carried out during the last solar cycle at balloon alti-

tude show that the total cosmic-ray intensity for magnetic rigidities above 1.5 Bv is reduced by a factor of 2 between the years 1954 (solar minimum) and 1958 (close to solar maximum). Similar results were obtained by a number of investigators [*Neher*, 1957; *Winckler* and *Peterson*, 1958; *Simpson*, 1959] (Fenton, Meyer, and Simpson, to be published). It has further been shown that both the α-particle component and the flux of heavier primary particles also undergo intensity changes which agree with the observations on protons within the experimental accuracy if the same rigidity intervals are chosen [*Freier, Ney*, and *Fowler*, 1958; *Freier, Ney*, and *Waddington*, 1959b; *Fichtel*, 1959].

An intimate relationship exists between the 11-year intensity variations and changes of the shape of the primary energy spectrum.

(a) The low-energy cut-off in the primary spectrum, whose existence has been known for many years, changes as a function of solar cycle and seems to completely disappear during the minimum of solar activity [*Neher* and *Stern*, 1955; *Meyer* and *Simpson*, 1955, 1957; *Neher*, 1957].

(b) The differential rigidity spectrum, which, between 1.5 and 5 BV, can be well described by a power-law spectrum of the form $N(R) \sim R^{-\gamma}$ changes substantially. While the exponent γ has been measured to be close to 2.0 during solar activity maximum for this interval of rigidity, it becomes approximately 2.7 in the years of minimum solar activity [*Meyer* and *Simpson*, 1955, 1957].

Detailed studies of the changes in the low-energy portion of the primary proton and α-particle spectrum during a portion of the past solar cycle were made by a number of investigators [*Freier, Ney*, and *Fowler*, 1958; *McDonald*, 1957, 1959; *McDonald* and *Webber*, 1959]. A close correlation between the variations in α-particle and proton spectra was found, and it was concluded that the same mechanism is responsible for the modulation of both components with an 11-year period. It has not been possible up to now to extend those measurements to a sufficiently low particle energy to be able to decide whether the modulation mechanism affects the particle rigidity or the particle energy. Present theoretical ideas favor a rigidity modulation [*Morrison*, 1956; *Parker*, 1956, 1958]. The 11-year cycle variation most likely affects a large volume surrounding the Sun-Earth system.

The Forbush-type decrease—A characteristic type of sharp decrease in cosmic-ray intensity was discovered by *Forbush* [1938]. This phenomenon follows large solar flares within one or two days and is frequently accompanied by a geomagnetic storm. During large events of this type up to 50% of the total cosmic-ray flux above 1 Bv rigidity reaching the Earth, may be removed within a few hours. It requires days or weeks for the particle flux to recover its normal value. The abruptness of the decrease has led to the suggestion that the mechanism responsible for this phenomenon may be located in the immediate vicinity of the Earth [*Parker*, 1956, 1958]. Recently, through measurements on the satellite *Explorer VI* [*Fan, Meyer*, and *Simpson*, 1960a] and space-probe *Pioneer V* (Fan, Meyer, and Simpson, to be published) it was established that the Forbush decrease extends with unchanged amplitude to large distances from the Earth. The observation on *Pioneer V* was made at a distance exceeding 5×10^6 km from the Earth, ruling out all models which invoke the presence of the Earth or its magnetic field for a description of the Forbush decrease phenomenon.

The behavior of heavier primary particles such as α-particles during Forbush decreases has been studied on various occasions. During the decreases of August 30, 1957 [*Meyer*, 1959] and May 12, 1959 [*McDonald* and *Webber*, 1960] (Meyer, to be published), a close correlation between the proton and α-particle flux has been found which points to a common modulation mechanism acting on both components. The largest sharp decrease in cosmic-ray intensity so far observed occurred on July 17, 1959. The α-particle flux for energies above 560 Mev/nucleon was measured at the time of minimum total intensity and was found to be depressed by 30 to 40% below its value before and after the Forbush event (Meyer, to be published). This number again agrees well with observations on the proton flux. There remains the problem of whether an energy-dependent or rigidity-dependent modulation mechanism is acting on the primary particles. The measurements so far do not extend to sufficiently low energies to discriminate between the two possibilities.

Cosmic Radiation and the Geomagnetic Field

Extrapolations from data obtained by magnetic surveys on the surface of the Earth have been used to calculate the magnetic Störmer cut-off rigidity for cosmic-ray particles. Various discrepancies between such calculations and experimental results were noted in the past few years.

(a) Measurements of the locus of cosmic-ray intensity minima near the Earth's equator [*Simpson* and others, 1956; *Katz* and others, 1958] yielded large deviations from the position of the geomagnetic equator.

(b) Direct measurements of the magnetic cut-off rigidities of primary particles at higher geomagnetic latitudes differed substantially from results based on Störmer theory and geomagnetic data [*McDonald*, 1957].

It has become clear from these experiments that the classical approach to use the dipole approximation for the Earth's magnetic field is not sufficient to describe the motion of cosmic-ray particles. This has led to a more detailed analysis of cosmic-ray particle trajectories including higher order contributions to the geomagnetic field [*Rothwell* 1958; *Quenby* and *Webber*, 1959] which seem to be capable to describe the major features of the cosmic-ray observations.

The results reviewed in this paper include only a fraction of the cosmic-ray work published in the United States during the past three years. We apologize for the omissions which could not be avoided within the size of this report. The developments in basic research are international and never rest upon the work done in one nation. This is especially true in a field like cosmic radiation. Therefore, a report on the U. S. effort in this direction can only represent a fraction of the total achievement in the years.

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PHYSICAL OCEANOGRAPHY

LEASON H. ADAMS, *Editor*

Equatorial Currents

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During the IGY and IGC the United States organized three expeditions lead by the author to study the equatorial currents of the Pacific (Table 1). The first of these was to study the Pacific Equatorial Undercurrent (the Cromwell Current) [*Knauss* and *King*, 1958; *Knauss*, in preparation]; the second and third were to study the Pacific Equatorial Countercurrent [*Knauss* and *Pepin*, 1959]. The results from these cruises, insofar as they are known, are summarized below.

The Cromwell Current—The Cromwell Current is a major feature of the oceanic circulation the presence of which was unsuspected ten years ago and the existence of which was not predicted by any of the theories of oceanic circulation. It is a thin, swift flow, centered on the equator and moving east beneath the west-flowing South Equatorial Current. As defined by the 25 cm/sec contour, it is 300 km wide and about 0.2 km thick; it is symmetrical about the equator (Fig. 1). At 140°W the core of the current is at 100 meters. Speeds up to 150 cm/sec (3 knots) were recorded. The average transport based on four

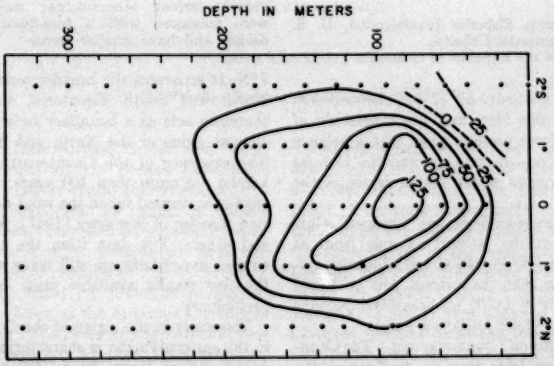

FIG. 1—Velocity cross section at 140°W; dots are observed points as measured by a modified Roberts meter lowered from a ship whose drift from a taut wire, anchored buoy was measured by radar; velocity is in cm/sec; eastward and westward flowing currents are plus and minus respectively

sections was 39 × 10^6 m^3/sec. The current was traced from 140°W to the Galapagos Islands at 92°W. It has not been found east of the Galapages. The core velocity was 100-150 cm/sec from 140°W to the Galapagos; in the same distance the depth of the core shallowed from 100 to 40 meters. At the surface and at 500 meters the flow was to the west.

The Cromwell Current is in approximate geostrophic balance. The horizontal pressure gradients appear to result from vertical mixing of the water at the equator and a breakdown of the sharp tropical thermocline. The mixing creates a meridional pressure gradient, symmetrical about the equator; hence, the Cromwell Current is a subsurface eastward flow which balances this gradient. All of the observational data support this idea, and the magnitude of the different force terms suggest that a balance between the pressure gradient and the Coriolis term exists even to within half a degree of the equator.

TABLE 1—*Expeditions to study equatorial currents of the Pacific during IGY and IGU*

Expedition	Dates	Ships
Dolphin	Mar. 27–June 10, 1958	*Horizon*[1] *Hugh M. Smith*[2]
Doldrums	Aug. 1–Sep. 30, 1958	*Horizon*[1] *Spencer F. Baird*[2] *Stranger*[1] *Almirante Padilla*[3] *Capitan Tono*[3]
Dorado	July 7–Aug. 20, 1959	*Horizon*[1]

[1]Scripps Institution of Oceanography, University of California.
[2]Pacific Oceanic Fisheries Investigation, U. S. Bureau of Commercial Fisheries.
[3]The Navy of the Republic of Colombia.

Direct measurements of the Cromwell Current show that the current extends from at least 92°W to 150°W (3500 mi). Indirect evidence suggests that the current will be found to at least 170°W (4700 mi long) and perhaps as far west as 160°E (6500 mi long).

Pacific Equatorial Countercurrent—The Countercurrent flows from west to east across the entire Pacific. It is relatively narrow, 300 to 500 km wide and is usually centered at about

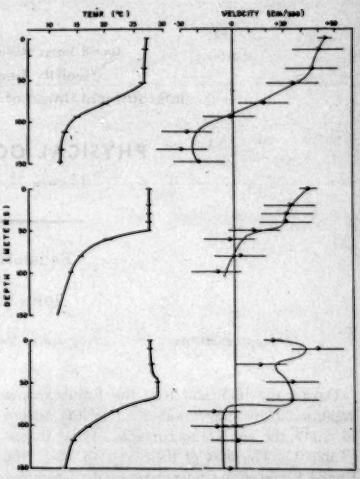

FIG. 2—Simultaneous profiles of temperature and velocity made in the Equatorial Countercurrent along 120°W; measurements were made by attaching an 'electronic bathythermograph' to a modified Roberts meter; measurement of temperature versus depth was recorded continuously; velocity measurements were made at selected depths and are marked in the temperature profile; horizontal lines on the velocity-depth curve indicate estimate of error of individual current observations; surface currents were measured with a free-floating parachute drogue and have smaller errors

7°N. It separates the broader westward flowing North and South Equatorial Currents, and therefore acts as a boundary between the great current gyres of the North and South Pacific. The existence of the Countercurrent has been known for more than 100 years, and its presence is accounted for in the wind-driven circulation theories of *Sverdrup* [1947], *Munk* [1950], and others. The data from the two Countercurrent expeditions are still being analyzed, and the few results available must be considered preliminary.

The water in the region of the Countercurrent in the eastern Pacific is characterized by a well-mixed surface layer, 30 to 100 meters thick, below which is a sharp thermocline, where the temperature can drop 10° in 30 meters. Direct

measurements have verified the geostrophic prediction that the velocity in the mixed layer is more or less uniform but drops sharply in the thermocline (Fig. 2).

Surface measurements in the Countercurrent indicate that the flow is not steady, and that the velocity can change markedly in periods of 12 to 36 hours. The mean value of the surface flow (averaged over periods of one to three weeks) ranges from 30–60 cm/sec. The instantaneous current can be descibed by the mean flow plus an irregular component whose root-mean-square scalar magnitude is half to two-thirds the mean velocity. Although the evidence is not clear cut, the data suggest that the water in the mixed layer flows in the same direction at any given time; that is, when the surface current goes southeast, all of the water in the mixed layer flows southeast.

Although the current velocities measured below the thermocline were much less than those measured in the mixed layer, the water transport below the thermocline can be relatively large, perhaps equal to that in the mixed layer. Such a transport was found in 1958 but not in 1959. The reason for the difference and the relationship between the currents above and below the thermocline is not yet clear. The observations from these three expeditions, however, have shown that the transports involved in any east-west water balance for this region are considerably larger than those previously estimated [*Sverdrup* and others, 1942].

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Antarctic Oceanography

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During the International Geophysical Year, systematic studies of the oceans have been initiated, most efforts of the United States program being concentrated in regions of middle and low latitudes. Only limited studies of oceanographic nature were possible in Antarctic waters as the main mission of the U. S. Navy Task Force 43 called for provision of logistic support to the bases on the Antarctic Continent. Except for the R.V. *Vema* of the Lamont Geological Observatory, Columbia University, no other U. S. oceanographic vessel entered the Antarctic Ocean. However, in spite of many restrictions much valuable data have been collected, especially from areas where previously no observations have been obtained [*Crary*, 1959]. Numerous hydrographic stations from the Weddell Sea and the Ross Sea have provided further evidence for the formation of Antarctic Bottom Water in these areas, which has been shown by *Lyman* [1958]. The highest density value ($\delta_t = 28.14$) ever observed in the oceans has been reported from the Ross Sea, where it was found near the bottom in 515 m depth [*IGY Bul.*, 1958]. Possible formation of Antarctic Bottom Water outside the areas men-

tioned above has been hypothesized by *Miller* [1959]. Unique observations were obtained near United States Antarctic IGY bases at Little America V and Hut Point, McMurdo Sound over a prolonged period of time giving us isopleth representation of several oceanographic parameters. A marked difference between the two stations has been found in their water-mass characteristics which is attributed to the different thickness of the ice shelf, from which the observations were taken.

On all ships which were engaged in the Antarctic Ocean an extensive program of bathythermograph observations was carried out resulting in several detailed temperature cross sections through the Antarctic Convergence which is becoming the object of increasingly intensified studies. Until recently the notion was commonly accepted that, as is indicated in the name, this phenomenon is associated with downward vertical motion. On the basis of several BT cross sections *Wexler* [1959] points to the possibility of upward vertical motion. This region of possible divergence in the surface layers has been related to the winter position of the pack ice boundary and the seasonal variations of the Westerlies.

The dynamics of the Antarctic Circumpolar Current as a wind-driven system is not very well understood. Difficulties in previous theories of zonal frictionally driven flow as applied to the Antarctic Circumpolar Current are still not removed. Attempts to correct these discrepancies (introduction of very high lateral-exchange coefficients) have been made by introduction of meridional motion assuming impediment to the pure zonal flow [*Stommel*, 1957]. It is more and more realized that the Drake Passage and the Scotia Ridge may have a stronger influence on the zonality of the flow and exert significant influence on the circulation in the Atlantic Ocean as well as in the Pacific Ocean. In this connection it might be useful to remember the unique position of the 'ocean' around Antarctica among all oceans as the communication link between the different parts of the hydrosphere, and the preferred role this 'ocean' plays as the region of sources and sinks of water-mass types.

The amount of water which is transported with the Antarctic Circumpolar Current around the Antarctica is believed to be approximately 110×10^6 tons sec^{-1}, as presented by *Sverdrup* and others [1942] almost 20 years ago. This value has been revised upward by oceanographers of other countries. However, these estimates are based on the most important assumption that the reference level can be found at the 3000 d-bar level or even at a deeper level. No clue or argument for this assumption has been so far given, thus these estimates must be regarded as preliminary.

The current United States program in the Antarctic calls for an expanded oceanographic observational program. Several cross sections of relative narrowly spaced hydrographic stations through the Antarctic Convergence are planned, as well as increased activity along the Ross Sea Ice Shelf, during the operation Deep-Freeze 60. These observations, if obtained as planned, will be among the best from the Antarctic Convergence region and may help to shed better light on this problem.

The recent development has been to place stronger emphasis on treating the ocean-atmosphere system as a unit. One step in this direction is the establishment of the Polar Meteorological Research Unit in the U. S. Weather Bureau, which is concerned primarily with heat- and water-budget problems in the antarctic and adjacent oceanic areas. Meteorological and oceanographical surface observations reported from the vessels of the U. S. Navy Task Force are one of the important sources of data for studies of heat exchange across the interface between the atmosphere and the ocean.

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Geochemistry of Ocean Water

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Whereas during the past three years much attention has been focused on the isotope chemistry of the oceans, the work of *Goldberg* and *Arrhenius* [1958], Wangersky of the University of Miami Marine Laboratory, and Turekian at Yale, and others, on the chemistry of the major and minor elements in deep sea sediments has demonstrated anew the complexity of sea-water chemistry and the need for far more detailed work in classical ocean-water chemistry. As part of their comprehensive paper Goldberg and Arrhenius attempt to define what fraction of a given chemical element found in deep-sea sediments was once in true solution in the oceans and what fraction is detrital. They point out that such estimates combined with sedimentation rates will ultimately lead to reliable values for the residence times of dissolved solids in sea water. *Garrels* and others [1959] have pointed out the importance of Na and Mg complexes in the carbonate ion equilibria in sea water stressing that many of the fundamentals of solution chemistry in sea water are yet to be defined.

The cycle of CO_2 in the atmosphere-ocean system has come under close scrutiny because of the potential warming in climate that could result from the addition to the system of carbon dioxide resulting from the combustion of coal and petroleum. Keeling and Rakestraw at Scripps, Takahashi at Lamont, and Hood of Texas A. and M. have carried out extensive surveys of the relationship between the partial pressure of CO_2 in surface ocean water and that in the overlying atmosphere. Combined with the work of *Kanwisher* [1959] at Woods Hole on the buffering effect in the ocean (rate of change of p_{CO_2} in ocean water with increasing total CO_2) a considerable advance has been made toward an understanding of the distribution of this man-made CO_2.

Numerous significant advances have been made in the applications of isotope geochemistry to the oceans. *Chow* and *Patterson* [1959] have demonstrated that the isotopic composition of lead in the oceans shows a marked regional pattern strongly suggesting that the residence time of lead in the oceans is sufficiently small compared to interocean and even intraocean mixing rates that variations due to source differences are not destroyed. Goldberg of Scripps has demonstrated that a similar pattern exists for the ratio of the thorium isotopes, Th^{230} and Th^{232}. Sackett and Potratz of Washington University of St. Louis have shown that Th^{230}, because of its very low concentration compared to that of U^{238}, must have a very short half-life in the oceans. *Walton* and *Broecker* [1959] of Lamont have demonstrated that whereas the rate of Th^{230} deposition in the equatorial Atlantic during glacial times and during post-glacial times was quite uniform, an abrupt two-fold decrease in rate occurred at the close of the Wisconsin 11,000 years ago. Roshalt of the University of Miami Marine Laboratory has tentative evidence for a constant ratio of Th^{230} to Pa^{231} in authigenic minerals deposited from sea water. If this proves correct it will constitute a major breakthrough in the field of age determination as applied to deep sea sediments.

Benson of Amherst is carrying out combined chemical abundance and isotopic abundance studies of the gases dissolved in the oceans. This type of study will yield valuable information to numerous phases of oceanography.

The study of cosmic-ray-produced isotopes in the oceans has progressed at an increasing pace. *Lal* and others [1960] have demonstrated the existence of measurable quantities of Si^{32} (half-life = 710 years) in oceanic sponges. As these authors point out, since the half-life of this isotope is the same order of magnitude as the mean residence times of water in the deep oceans, it should prove extremely useful in the study of oceanic circulation. *Koczy* [1958] has shown the potential of Ra^{228} (1600 year half-

life) in circulation studies. This isotope is released from bottom sediments where it is produced by the decay of Th^{230}. Since the cosmic ray and fallout isotopes are all added to the surface of the ocean, the contrast provided by the Ra^{226} cycle should prove extremely useful.

Studies of the distribution of radiocarbon in the Pacific and Atlantic Oceans have been carried out respectively by *Suess* and others [1959] at Scripps, and *Broecker* and others [in preparation] at Lamont. The Pacific deep-water measurements yield the lowest C^{14}/C^{12} ratios as yet found in the oceans (20% lower than that in atmospheric CO_2). Because of the low values found in the surface water of the Antarctic (−10%) the residence times based on C^{14} data may prove to be no more than 800 years. For comparison the Atlantic deep waters of northern North Atlantic origin appear to have residence times of about 650 years and those of Antarctic origin less than 300 years. Two other interesting features of the Atlantic C^{14} distribution are the south to north increase in the C^{14}/C^{12} ratios of surface water and a C^{14} maximum layer between 1200 and 2400 meters in the western North Atlantic corresponding perhaps to the recently discovered western boundary current.

Both particulate (Sr^{90}, Cs^{137}, . . .) and gas phase (C^{14}, H^3, . . .) fallout should prove quite useful in circulation studies in the ocean (especially for those reservoirs communicating with the surface on a time scale of tens of years). *Bowen* and *Sugihara* [1958] have presented results on Sr^{90}, Ce^{144}, and Pm^{147} in the surface and near surface water of the Atlantic and *Broecker* and *Olson* [in preparation] have discussed the distribution of bomb-produced radiocarbon.

Whereas the above is by no means a complete and perhaps not a properly weighted summary of the research in progress in the United States on ocean chemistry, it does at least provide some idea of the scope of such work.

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Surface Waves

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United States scientists are studying surface waves as generated by wind with a combined observational and theoretical approach. Wave amplitudes, wave slopes and wave accelerations either have been or are being measured as a function of time at a fixed point, often with concurrent wind-profile measurements. Waves have been studied at an instant of times as measured from stereo photographs over an area. These records have been analyzed as a stationary random process in time and space, and spectra have been obtained by both analogue and digital techniques. The theoretical problem of providing an explanation for the wide variety of spectra has had a number of significant developments.

The very high frequency waves, where surface tension is important, have been studied in wind tunnels with lengths shorter than one meter [Schooley, 1958], about three meters [Cox, 1958a], and over six meters (New York University, unpublished). Effects at frequencies from 100 cycles per second to 10 cps to 1 cps have been detected, and strong non-linear features at wavelengths near 2.44 cm have been demonstrated. Significant heights ranged from 0.05 cm to 0.5 cm and mean-square slopes ranged from 0.01 to 12.

At intermediate frequencies, waves have been measured in Chesapeake Bay (Kinsman, unpublished), along with wind profiles and air-water temperature differences over a range of frequencies from 0.5 to 5 cycles per second. Waves have been measured in Buzzards Bay (H. G. Farmer, unpublished) under similar conditions, and sharp discontinuities in slope have been found at the crests along with evidence that some of the waves were actually breaking as they passed the probe.

At moderate frequencies, waves have been measured at the New York Texas tower (U. S. Navy Hydrographic Office, unpublished) by means of both wave wire and accelerometer rafts with fair agreement. Accelerations have been measured by means of a small telemetering expendable raft (Marks, unpublished) [*Tuckerman*, 1960] and related with considerable accuracy to shipborne wave recorder [*Tucker*, 1956] records. The SWOP project [*Chase*, and others, 1957] obtained stereo photographs, computed the two-dimensional wave-number spectrum and compared the results with a spectrum from a wave-pole record with imperfect agreement. The SWOP results have been re-evaluated in the light of new theoretical results to be discussed below (unpublished).

The wind-generated waves on the open ocean are important with respect to problems of naval architecture. Oceanographers have cooperated with naval architects in solving a number of problems of importance. A symposium on ship motions was held at Wageningen. Numerous papers and discussions of these papers were published [*Symposium*, 1957]. In addition, papers by *Cummins* [1959] and *Tick* [1958, 1959a] are of interest. Studies of waves needed to aid in improving the design of ships have been described [*Lewis* and *Gerard*, 1959]. An analogue spectrum analyzer for the multichannel analysis of vector processes in connection with wave and ship motions has been developed by *Marks* and *Strausser*, [1959].

Waves of very low frequencies of the order of a centimeter or so in height with frequencies over a range from 0.001 cps to 0.011 cps and then merging into swell and wind wave frequencies have been studied by *Munk* and others [1959]. Very sensitive instrumentation and refined computation techniques had to be employed in this study. Longer period ocean waves have also been recorded on a continuous basis as a number of sections in the north Atlantic by *Donn* [1959ab] during the IGY.

As in many other fields, refined measuring techniques and greater availability of data have intensified theoretical investigations. The sta-

tionary random short-crested Gaussian sea surface has served as an adequate linear model in many problem areas such as ship motions. It also seems capable of describing the properties of the bottom pressure fluctuations caused by gravity waves [*Ehrenfeld* and others, 1958].

However, non-linear problems are increasingly pushing to the forefront. The highest waves in a random sea, limited by breaking, are important in naval architecture. Slopes and curvature appear to have decided non-linear features. Non-linearity may prove to be one of the dominant factors in the determination of the wave spectrum. One can distinguish crests from troughs in a random sea in the sense that an upside down sea surface could be immediately recognized.

The analysis of *Phillips* [1958a] on the high frequency behavior of the wave spectrum is essentially non-linear and leads to the possibility that other, somewhat more empirical, theoretical spectral forms that differ from each other are consistent for the conditions under which they were studied [*Pierson*, 1959]. A start toward the development of a non-linear random model for gravity waves has been made [*Tick*, 1959b].

Important contributions to the theory of the generation of waves by wind have been made by *Phillips* [1957, 1958b] and *Miles* [1957].

The problem of wave forecasting is still unsettled. Agreement between different procedures is lacking. These different procedures are however being compared with each other and against actual observations [*Bretschneider*, 1959; *Darbyshire*, 1959, *Neumann* and *Pierson*, 1957, *Pierson*, 1960, and *Walden* and *Farmer*, 1957]. The height of the highest waves that can be generated by wind of constant velocity blowing for a long enough time over a great enough distance is not agreed upon.

Although this summary is brief, it does reveal some of the dominant areas of interest. Additional material not specifically mentioned above is included in the references.

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Internal Waves

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Advances in understanding the significance of internal waves in the sea have proceeded along several lines. *Haurwitz* and others [1959] have examined long-term temperature records from thermisters fixed at depths of 50 and 500 m off Castle Harbor, Bermuda. The data are remarkable for the complete lack of coherence between the two temperature traces and by a large degree of variability. There is evidence for increase of temperature unrest following the passage of storms. Tidal periodicities in the variations of temperature have been barely detectable in the data because of the large background of fluctuations having a broad spectral distribution. Above a frequency f of 0.75 cycles per hour the energy spectra decrease faster than f^{-2} and Haurwitz, Stommel, and Munk relate this rapid cutoff to the Vaisala frequency

$$N = (2\pi)^{-1} (g\rho^{-1}d\rho/dz)^{1/2}$$

Analysis by *Lee* and *Cox* [in preparation] of records of isotherm depths measured off Mission Bay, California, has a bearing on this point. These analyses were carried to frequencies higher than the maximum Vaisala frequency N_m of the water column, but although the spectra of variations of isotherm depth decreased with increasing f there was no pronounced cutoff above $f = N_m$. The California measurements were carried out simultaneously at three stations forming an equilateral triangle with sides 120 m long. Coherence between the various records shows conclusively the existence of progressive internal waves for $f < N_m$ and the lack of coherence for $f > N_m$ shows that temperature fluctuations of these high frequencies are associated with turbulent convection. At the same location in California as well as in Indian waters *LaFond* [1959, 1960a] has found a close connection between the existence of internal waves and band slicks (Fig. 1) on the surface of the sea.

LaFond [1960b] has also described a fixed tower for studies of internal waves and other observations in shallow water. Another interesting instrumental development is the thermister chain constructed at the Woods Hole Oceanographic Institution. The instrument consists of a chain of thermisters hung in the ocean. Through use of an interpolating device, a chart showing the depth of isotherms is automatically prepared (Richardson, personal communication). *Frasetto* [1959] has used this device in

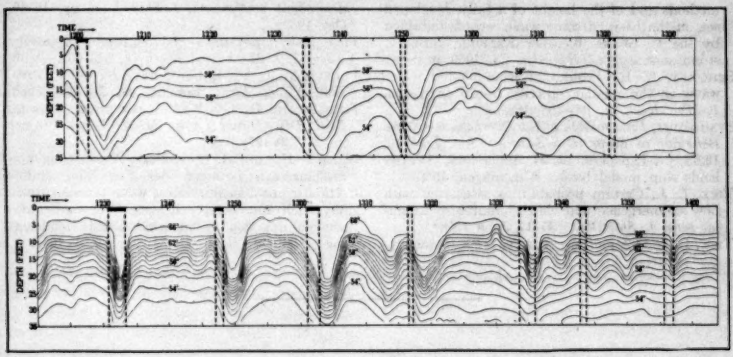

FIG. 1.—Relation of slick bands (heavy lines at surface) and isotherm depths observed off Mission Bay, California. Slick bands are associated with convergence zones in front of internal wave troughs

the Straits of Gibraltar to find details of tidal and higher frequency oscillations.

Following the observations by *Reid* [1956] of large internal oscillations of tidal periods, *Rattray* [1959] and *Cox* [1959] have considered the possibility of coupling between internal waves and the ordinary surface tide. Rattray considers coupling by interaction with surface currents and bottom irregularities, and Cox by bottom irregularities alone. There are suggestions in these calculations that the amount of tidal energy flowing into internal oscillations is sufficient to cause appreciable damping of the tide.

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Tsunamis

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A survey of the recent literature makes it appear that most of the research devoted to tsunamis within the United States within the past three years has been carried out by two groups at the Scripps Institution of Oceanography. This lack of published literature is, perhaps, misleading, in that it is known that the U. S. Coast and Geodetic Survey continues its long-standing efforts to document tide-gage records of tsunamis and to increase the effectiveness of its tsunami warning service in the Pacific, and it is my understanding that the results of a survey of local wave inundation heights in the Hawaiian Islands following the tsunami of March 9, 1957 will be published soon by J. Eaton and others, under the auspices of the Institute of Geophysics of the University of Hawaii. Additionally, this group, together with D. C. Cox, Geologist for the Hawaiian Sugar Planters' Association, are making a study of the oscillations in water level in wells in Hawaii associated with seismic disturbances. These oscillations appear to be local resonances excited by Rayleigh waves, and the possibility exists of calibrating wells as a measure of relative seismic intensity, which in turn is related to tsunami production.

At the Scripps Institution a group under W. H. Munk has analyzed surface-wave spectra from some 80 records [*Munk* and others, 1959] including several tide gage records of tsunamis. Such tsunami records exhibit local energy densities some 10^4 times larger than local background, but strongly reflect local resonances, making the interpretation of the records difficult, if not impossible. He concludes that tsunami records from small isolated islands can faithfully reproduce incoming signals for wavelengths large compared to the island diameter.

A second group headed by W. G. Van Dorn has just completed a four-year study of tsunamis and related long-period waves under contract with the Office of Naval Research. This study was an outgrowth of long-wave studies conducted previously during nuclear tests at the Pacific Proving Grounds. Long-wave stations were set up and operated on a temporary basis for about two years on eight small Pacific Islands, in hopes of obtaining records from at least one large tsunami, as well as that as possibly detecting the existence of small and previously unnoticed tsunamis from lower-intensity quakes. Nine field crews were established around the Pacific in areas having a known susceptibility to previous tsunamis with view to making detailed inundation surveys in the event of a large tsunami. These efforts were rewarded somewhat prematurely during the installation phase of the program by the occurrence of the large tsunami of March 9, 1957. Adequate records were obtained from Wake, Canton, and Kona, Hawaii, and a great deal of inundation data were collected from Samoa, Tahiti, the Aleutian Islands, Kamchatka, Japan, and particularly, in the Hawaiian Islands. These data, together with those from the bomb tests, permit the construction of a fairly consistent model for this tsunami, and one which is considerably at variance with that previously inferred from tide gage observations. The results have been discussed in an interim report under the ONR contract [*Van Dorn*, 1959], and will be published as a series of papers this year.

The results obtained with temporary recorders strongly indicate the desirability of continuing long-wave observations. Three permanent stations are now planned for installation in the spring of 1960 at Wake, Johnston, and Canton Islands, under support from the Office of Naval Research, the National Science Foundation, and the U. S. Weather Bureau. These stations will be equipped to monitor subsurface

water temperature, wind-speed and direction, and microbarometric pressure, in addition to long-period waves.

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Storm Surges

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The major storm-surge problem in the United States is the short duration rise in sea level accompanying the landfall of severe tropical cyclones.

The low pressure, high winds, and waves near the center of these storms lead to increases in sea level of as much as 15 feet above normal on the open coast for the time and place at which the storm crosses the coast. The extremely high tides rarely extend over more than 100 miles of coast line. The region seriously affected is often smaller [*Harris*, 1958a]. Along the open coast the extremely high water rarely persists more than a few hours. In inland regions with poor drainage the high water may persist for several days. The highest surge generally occurs near the region of maximum onshore winds to the right of the storm center, but significant surges frequently develop to the left of the center. Below normal sea levels sometimes occur to the left of the storm center and before the storm center approaches the station. Below normal sea levels frequently develop after the storm is past.

The surge accompanying Hurricane Audrey has been described in detail by *Harris* [1958b]. A more general description of the hurricane surge problem is given by *Harris* [1958a]. The meteorological aspects of the hurricane surge problem are discussed by *Harris* [1958c] and *Dunn* [1958].

The study of the meteorological causes of the hurricane storm surge has been greatly facilitated by the publication of tracks by *Cry* and others [1959]. *Graham* and *Hudson* [1960] have reconstructed the surface wind and pressure fields of 15 hurricanes and three extratropical storms especially for storm surge studies. These have been used in several of the reports discussed below. *Graham* and *Nunn* [1959] have developed a generalized model for the surface-wind and pressure profiles and have given empirical distribution functions of the parameters of the model for use in estimating the maximum probable hurricane surge at any location along the Atlantic and Gulf Coast of the United States.

Kajiura [1958a] used the methods of classical physics to investigate the surge produced by a circularly symmetrical hurricane on a boundless two layer ocean. *Reid* [1958] and *Kajiura* [1958b] extended the edge wave theory to include the effects of Coriolis force with a view to improving this theory as a means for investigating the generation of storm surges by hurricanes. *Wiegel* and others [1958], and *Abraham* [1959] have conducted model studies of the gravity waves generated by moving circular low-pressure areas with a view toward duplicating as closely as possible conditions leading to the formation of hurricane storm surges in a hydraulic model.

There are many qualitative similarities between the results of the theoretical studies mentioned above and observations of natural phenomena. However, the quantitative agreement

between theory and observations is not yet satisfactory for engineering design or forecasting.

Several investigators, attempting to avoid the difficulties inherent in idealized models, have obtained numerical solutions of the equations of motion. The simplest of these numerical solutions is given by *Bretschneider* [1958]. He performs a steady state integration of the shoreward component of the wind stress from deep water to the coast line, taking into account the total depth and the bottom friction, but neglecting all other non-linear and two-dimensional features of the problem. This technique and the data given by Graham and Hudson, and Graham and Nunn have been used to make preliminary estimates of the maximum probable storm surge for engineering applications at many locations [*Bretschneider* 1959ab]. *Reid* [1957ab] has developed a more sophisticated one-dimensional model suitable for relatively deep narrow channels. This model can reflect the variations in the speed of the hurricane center as well as in the speed of the wind. It also has been used for engineering design purposes.

An attempt to develop a two-dimensional model based on the method of characteristics, by *Freeman* and *Baer* [1957], did not prove to be feasible in practice and the authors later introduced a quasi-two-dimensional model [*Freeman* and others, 1957], in which flow toward the shore and all derivatives along an axis parallel to the shore are neglected. This simplification permits replacement of the partial differential equations by a set of definite integrals, while retaining at least some effects of the Earth's rotation. The inclusion of the Coriolis term is a definite improvement as it permits surge heights to increase in regions having offshore wind components. However, it requires more accurate knowledge of the wind field, while the storm is still at sea, than the meteorologist can often supply.

Platzman [1958] has developed a two-dimensional linearized storm surge model for the IBM 704. This model has been used to investigate the storm surges caused by line squalls on Lake Michigan, and is being extended to an investigation of the surges developed along the open coast by hurricanes.

All of the mathematical models described above are based on the assumption that the horizontal velocity components in the water can be adequately represented by their vertically integrated mean values and that the law relating wind stress to wind velocity is well known. The extent to which this condition holds has been investigated by *Tickner* [1957] and *Reid* [1957ab].

There has been considerable speculation, though little quantitative information, concerning the possibility that the breaking waves generated by hurricanes in shallow water are responsible for a considerable fraction of the hurricane storm surge. *Pore* [1957] failed to locate any quantitative data for confirming this hypothesis. *Fairchild* [1958], in a model study of hurricane wave conditions in Narragansett Bay, found that the water transported by waves in shallow water could result in a water level on the beach as much as three feet higher than that experienced one mile seaward. An adequate theory for the reliable estimation of the extent of wave set-up, as this phenomenon has been called, is yet to be developed.

The first and simplest of several empirical approaches to the hurricane surge problem was developed by *Conner* and others [1957]. In this development the maximum storm surge for Gulf of Mexico hurricanes has been related to the central pressure in the storm. Data from Atlantic Coast storms are plotted on the resulting prediction graph and it is shown that the data from the two sources are compatible. *Hoover* [1957] performed a similar analysis, but idealized the storm-surge profile along the shore line as a function of location of the storm and angle between the shore line and storm track. The idealized storm-surge profiles permitted the use of extrapolation to estimate the peak surge for storms in which this quantity was not observed and the stratification of cases improved the correlations between the peak-surge estimates and the central pressure.

The approach described above was extended by *Harris* [1959] to take into account the slope of the continental shelf and to use data obtained after publication of the 1957 paper. The resulting equation takes the form

$$h = 0.6213(1025 - P_s)^{1.132}S^{0.088} \qquad (1)$$

where h is the peak storm surge on the open coast in feet, P_s is the central pressure of the storm in millibars and S is the distance from the coast to the 50 fathom depth contour in

nautical miles. The standard error of this formula as applied to the 52 dependent cases is 2.1 feet.

Wilson [1959] developed an empirical prediction system for New York Harbor in which the tide at the harbor entrance is expressed as a function of the wind and pressure at the harbor entrance and the onshore component of the wind at five other locations. He also gives regression diagrams for computing the surge at many locations within the harbor when the surge at the entrance is known.

A comparison of theoretical results and observations is given by *Kajiura* [1959]. He restricted his attention to those cases in which the storm surge could be accurately determined as the difference between observations and first order predictions. In this manner he minimized the possibility of using misleading data, but necessarily rejected much useful data. It appears that he has made a start in the problem of bringing order out of chaos, but many of his results may be biased by the accidental selection of data he was forced to use.

It is interesting to note that most of the results of the other computation schemes discussed above agree with the results of Eq. (1) within the probable error of the later equation whenever they have been compared.

Tancreto [1958] demonstrated that extratropical storm surge at Boston correlates well with the forecasted significant wave height in the vicinity of Boston as computed by the Sverdrup-Munk-Bretschneider technique. *Donn* [1958] has investigated the relationship between winds and the departure of the observed and predicted high and low tides at six locations between Atlantic City and Boston. *Miller* [1958] investigated the relationship between winds and short-period means of sea level in Nantucket Sound. A numerical filter was used to eliminate tides from the observations in this study and hence the peak values of the surge were underestimated. Nevertheless, Miller was able to distinguish between local effects which differed from one station to the next in the vicinity of the sound and large-scale effects which were nearly the same at all stations in the vicinity of the sound.

In an investigation of storm surge on Lake Erie, *Hunt* [1958, 1959] found that agreement between the observed and predicted surge elevations was improved by considering the stability of the air as well as the wind velocities.

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Marine Seismic Studies

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The past three years have been a period of great activity in seismic studies of the ocean floor. These studies form part of a program carried out during the past decade principally by three scientific institutions in the United States: the Lamont Geological Observatory of Columbia University (LGO), the Woods Hole Oceanographic Institution (WHOI), and the Scripps Institution of Oceanography of the University of California (SIO). The most noteworthy event of the period 1957–1960 was the occurrence of the IGY, which stimulated greater geographical exploration than had heretofore been attempted. Another significant event was the formation of the AMSOC Committee of the National Academy of Sciences for the drilling of a hole to the Earth's mantle, a project which received the endorsement of the Eleventh General Assembly of the International Union of Geodesy and Geophysics in Toronto, 1957. The structural information guiding the choice of a drilling site depends largely on marine seismic-refraction observations. Hence the drilling project has stimulated the careful scrutiny of past data and has been responsible for further detailed studies in regions being considered as possible drilling sites.

The marine seismic measurements were car-

ried out on oceanographic research vessels along with other related geological, geophysical, and geochemical observations, such as echo sounding, bottom coring and dredging, water sampling, heat-flow studies, continuous geomagnetic profiling, and gravity measurements. Most of the seismic results were obtained with refraction measurements, which have been found to yield much more knowledge of crustal structure than reflection measurements. However reflection studies were also made along with the refraction studies and furnished additional data under favorable conditions.

The geographical extent of these operations was impressive. Some work was done in all of the oceans of the world; and although the world coverage was far from complete, the operations were essentially global in scope. It would not be possible in this summary to describe all of this work in detail even if it were known to the writer, who is acquainted with only a fraction of what has been accomplished. Although a few preliminary results have been circulated, detailed knowledge awaits final study and publication.

During IGY, the LGO, partly in collaboration with WHOI and partly with the help of research vessels and scientists of Brazil, Argentina, and the Union of South Africa, conducted the most extensive and detailed series of refraction measurements yet undertaken. The areas studied were the Caribbean Sea, the continental border of South America from Buenos Aires to the Scotia Sea well south of Cape Horn, the Cape of Good Hope area, the Indian Ocean, the Gulf of Aden, the Red Sea, and the Mediterranean Sea.

In this work 199 seismic refraction stations were occupied. This is only part of the work accomplished by LGO and WHOI during the period 1957–1960 although the total amount is not known to the writer. It is estimated that it is about half of the total. In May and June 1959, a cooperative seismic-refraction study of the region extending roughly 300 nautical miles northerly from Puerto Rico was conducted by ships of four institutions: LGO, WHOI, Texas A&M College, and the Hudson Laboratories of Columbia University. This concentration of ships and seismic profiles into a small region was for the purpose of a thorough study of the crustal structure down to the base of the crust in a region being considered as a favorable site location for drilling to the mantle.

In the Pacific, the IGY effort of SIO was concentrated in one major expedition, Downwind, which was devoted principally to exploring the southeast Pacific as far as latitudes 45°S between Tahiti and the coast of South America. Thirty-nine refraction stations were occupied, including such varied regions as the Easter Island Rise, the South American Trench, the Tuamotu Ridge, Nasca Ridge, and including numerous deep-sea stations widely distributed throughout the region. In three expeditions before and after Downwind seismic refraction measurements were carried out in the northeast Pacific up into the Bering Sea, along the continental border off southern Alaska, off California and Mexico from latitude 20 to 41°N including a series of 16 stations in the Gulf of California. This work involved 73 receiving stations giving a total of a little more than a hundred stations in the Pacific during the 1957–1960 period. In the latter part of this period in July and August 1959, refraction and reflection studies were made of the deep sea immediately off California and northern Mexico to provide information for the deep-sea drilling project.

It will be some time before we will know all of the results of these extensive studies of the large variety of refraction profiles recorded. Some preliminary results have already appeared and tentative conclusions have been made in the references cited. Our knowledge of the oceanic crust has been substantially increased by the marine seismic studies of the past three years. The coverage of the sea floor has approximately doubled during this period. The data obtained will support significant conclusions regarding several problems of fundamental importance to problems of the history and development of ocean basins. Some of these problems are: (1) structure and variability of the 'typical' deep-sea crust; (2) crustal structure of trenches, such as those found west of South America and north of Puerto Rico; (3) structure of the transition between continent and ocean at a wide variety of interesting situations including the east and west coasts of South America, South Africa, east and west coasts of North America, and Arabia; (4) structure of large quasi-oceanic seas such as the Mediterranean Sea and the

Caribbean Sea; (5) Structure of narrow, intracontinental seas, such as the Red Sea, Gulf of Aden, and the Gulf of California; (6) structure of oceanic ridges and rises, including the Mid-Atlantic Ridge, Easter Island Rise, and Nasca Ridge; and (7) structure of islands and atolls, such as the Tuamotu and Caribbean Archipelagos.

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Gravity at Sea

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The technique of measuring gravity at sea has been revolutionized in the last three years by the development of meters able to work successfully on surface ships. The rate of accumulation of data has been increased by an order of magnitude and the potentialities are even greater.

There were signs of the impending revolution at the Toronto meeting of the IUGG in September 1957. A day's discussion was devoted to the measurement of gravity at sea and this discussion brought forth descriptions of two sea-going gravity meters, developed by *Graf* [1956, 1957, 1958] and by L. J. B. LaCoste. Successful tests of both meters on board submarines were described [*Worzel* and *Graf*, 1957, *Spiess* and *Brown*, 1958] and there was no fundamental reason apparent why these meters could not be improved to operate under the more disturbed conditions experienced on surface vessels. J. L. Worzel made the first gravity measurements on a surface ship in the open sea using Graf's meter on board the USS Compass Island in November 1957 [*IGY Bul.*, 1958]. LaCoste's meter was successfully operated on a surface ship in the spring of 1958 [*LaCoste*, 1959] and both meters were extensively used and tested during 1958 and 1959.

Gravity meters for use at sea must be heavily damped so that the beam does not hit the stops in the presence of large vertical wave accelerations. Further the meter must be very stable, as several weeks or even months may elapse between checks at base stations. A meter for use in the presence of large horizontal accelerations must either be stabilized along the true vertical and be constructed so that it is not affected by horizontal accelerations, or it may be suspended in gimbals and allowed to swing to follow the total apparent acceleration. In the latter case it is necessary to subtract a correction, because the quantity measured is the total resultant acceleration which is always greater than the vertical component. The Graf meter has no means of computing the necessary correction and has been used with a stable platform. The LaCoste-Romberg meter has accelerometers for measuring the horizontal accelerations and the appropriate correction can be computed electrically and applied automatically. This meter can be used either suspended in gimbals or, with the horizontal correction circuits disconnected,

on a stable platform. So far it has always been used in a gimbal suspension.

Each method of operation brings its own difficulties and the theoretical considerations have been summarized by *Harrison* [1960]. In obtaining gravity-meter readings to 1 mgal on land it is only necessary to level to an accuracy of five minutes of arc, but when operated in the presence of horizontal wave accelerations it is necessary to avoid stabilization errors with the same period as the waves of much smaller amplitude than this. For horizontal accelerations of 100,000 and 10,000 mgal amplitude, it is necessary to keep the amplitude of the stabilization errors below 4 and 44 seconds of arc respectively. LaCoste has pointed out that there is also a cross-coupling effect between the horizontal and vertical accelerations. The meter beam is deflected by the vertical accelerations and the horizontal accelerations acting on the deflected beam produce a couple which may be consistent in direction depending on the various phase angles involved. In the case of circular motion, the effect is at its maximum for a meter whose beam has its undamped free period equal to the wave period. This effect can be reduced by slow rotation of the meter about a vertical axis.

LaCoste has also investigated the case in which the meter is free to swing in gimbals. The correction for horizontal accelerations takes an especially simple form ($\frac{1}{2}$ g θ^2 where θ is the deflection from the vertical of the meter in its gimbal suspension) when the sensing element is positioned a distance below the gimbals equal to the length of the simple pendulum with the same period as the meter in its gimbal suspension. The cross-coupling effect is not important.

After the initial tests in November 1957, Worzel was able to make a five-week cruise on the *Compass Island* from New York to the Mediterranean in March and April 1958. It was possible to obtain continuous observations 90% of the time in the Mediterranean and 50% of the time in the Atlantic. In August the opportunity arose to make many repeat runs along the New York line of submarine gravity observations. The reproducibility and agreement with pendulum values are good, as can be seen from the published results [*Worzel*, 1959].

The *Compass Island* is a ship of 18,000 tons fitted with fin stabilizers and opportunities for using such ships for oceanographic work are few and far between. The Graf sea gravimeter installed on a jury-rigged stable platform on R. V. *Vema* has been obtaining gravity measurements at sea about 10 to 15% of the time the *Vema* is at sea. On the *Vema* 15, observations were made on the track from Buenos Aires to Recife, from Recife through the Windward Islands into the Caribbean to Puerto Rico, from Puerto Rico to the Bahamas through Northwest Providence Channel, several tracks through the Florida Straits and thence north to New York. Especially noteworthy is a continuous track across the Puerto Rico Trench in the vicinity of Barbados from well out to sea to well into the Caribbean. In the area of the Bahamas and the Florida Straits records were obtained nearly 100% of the time. A large seismic shot fired in the vicinity of Buenos Aires caused a ligature to break. There were zero shifts each time the meter was clamped after this event. The relative gravity values for each period of remaining unclamped appear to be satisfactory despite the broken ligature.

For *Vema* 16, the ligatures have been replaced. The new stable platform had not been completed, so it was necessary to send the Graf sea gravimeter to sea still mounted on the jury-rigged stable platform. Observations have been obtained about 10% of the time *Vema* has been at sea on the course between New York to Bermuda to Puerto Rico, from Puerto Rico to Recife and from Recife to Capetown.

In cooperation with the Union of South Africa, arrangements were made to install the Vening Meinesz Pendulum apparatus on H. M. S. *Acheron*. Thirty-nine gravity observations were made on the track from Sierra Leone to Capetown to Durban to Karachi through the Mozambique Straits.

After the initial tests of the LaCoste surface meter on the Texas A and M College ship, the *Hidalgo*, a converted minesweeper 136′ in length, measurements were taken on a 300-mile track off Southern California which passed close to twelve submarine stations [*Harrison*, 1959]. The University of California's research vessel, *Horizon*, of 505 gross tons was used. The root-mean-square difference between the submarine and surface measurements is 4.4 mgal, which is about the uncertainty introduced by the inaccuracies of navigation. In order to eliminate

these inaccuracies from the next tests of the meter, made on board the *Horizon* during a survey of the Gulf of California, 27 simultaneous readings were taken with a remote-reading underwater meter on the sea bottom and with the surface meter. There was a consistent difference of 2.6 mgal between the two sets of readings but the scatter from this mean difference was only 1.5 mgal. The gravity survey of the Gulf consisted of continuous profiles at about 10-mile intervals and readings were possible for approximately 50% of the time in the southern half of the Gulf and practically the whole time in the northern half. The Institute of Geophysics of the University of California has continued working off the west coast of North America and the area between latitudes 29 and 34°N is now mapped with continuous profiles spaced no wider than 10 miles apart out to about 80 miles from shore in the northern sector and out about twice as far in the southern.

Most promising tests of the LaCoste-Romberg meter have been made in aircraft. The meter is certainly capable of making good airborne measurements under quiet atmospheric conditions and the problem of making accurate airborne gravity measurements is now one of determining the airplane's horizontal and vertical velocities with sufficient accuracy. The first tests were made by Thompson and LaCoste on board a USAF KC-135 over Edwards Air Force Base, California [*Thompson*, 1959, *Thompson* and *LaCoste*, 1960]. Precise navigational data were obtained from the airplane by a Doppler radar system with barometric measurements for elevation changes, and from the ground by photo-theodolites. Further tests were made by *Nettleton* and others [1960] on board a B-17 airplane over the Imperial Valley of California in May 1959. Horizontal navigational control was obtained from aerial photographs taken at about 20-second intervals and vertical control was obtained from a precision radar altimeter and a hypsometer. It appears from the latter tests that a 3-minute reading, corresponding to about 10 miles covered over the ground, is accurate to about 10 mgal. The value of airborne surveys for making rapid regional surveys of the oceans depends on whether a suitable navigational system can be evolved.

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Sea Floor Relief

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The years 1957–1959 have seen widespread use of precision sounders by U. S. oceanographers. These instruments, with an accuracy of one fathom at any depth, leave position as the only uncertainty in making bathymetric charts. Electronic navigation techniques have been used in many places off the United States for distances of several hundred miles from shore. Only a few of the resulting charts have been published [*Jordan* and *Stewart*, 1959], but they reveal details of relief which previously were not contourable. Far from land, taut-line moorings have been used as local reference points for detailed surveys of seamounts and low relief.

The Aleutian, Middle America, Peru-Chile, [*Zeigler*, and others, 1957] Marianas, Puerto Rico, and South Sandwich trenches have been surveyed or explored during the past three years. The first five of these trenches have flat floors in some places, and the one in the Aleutian Trench is continuous for more than 1000 miles.

Topographic provinces have been delimited in several regions where soundings are very abundant, even though only a few precision echograms are available. The North Atlantic consists of many provinces which are parallel to and symmetrically disposed around the Mid-Atlantic Ridge [*Heezen*, and others, 1959]. The crest of the Ridge is marked by an almost continuous median trough which is seismically active. The ridge itself has a central mountainous province formed by block faulting. At the base of the continental slopes are abyssal plains and these are separated from the Mid-Atlantic Ridge by small regions with abyssal hills. The South Atlantic has roughly the same configuration although several 'median' rifts exist. The median elevations in the ocean basins are essentially continuous [*Ewing* and *Heezen*, 1955] but the general character of the topography changes from place to place [*Menard*, 1958]. Most notably the median rift which exists in the Atlantic and Indian oceans appears to be absent in the Pacific except south of New Zealand. Instead, the continous East Pacific Rise is cut by major lineations (fracture zones) intersecting the rise at approximately right angles to the general trend [*Menard* and *Fisher*, 1958]. The fracture zones off North America have lateral displacements of 100 to 200 miles [*Mason*, 1958], and minor lineations indicate that the crustal blocks between the zones have been distorted uniformly [*Menard*, 1959a].

Most volcanic island groups rise above a ridge which is circled by a moat which commonly is filled with an archipelagic apron. Elegant examples of these structures exist around the southern Hawaiian Islands [*Hamilton*, 1957]. More than 1000 seamounts are known, and several means of estimating agree on 10,000 as the total number in the ocean basins [*Menard*, 1959b]. Consequently, seamounts are discovered on every expedition. In contrast, the number of known guyots, or drowned ancient islands, has not increased significantly in the 14 years since they were discovered. It appears that they are characteristic only of the central western Pacific, although small groups exist in all the oceans.

Exploration of abyssal plains has continued and the world-wide distribution established [*Elmendorf* and *Heezen*, 1957]. Surveys of plains in the Gulf of Mexico [*Ewing* and others, 1958] and the Arctic Basin [*Fisher* and others 1958] confirm the already well-established theory of origin by deposition from turbidity currents. Similar confirmation is given by the correlation between the distribution of sand and the shape of deep-sea fans off Southern California [*Gorsline* and *Emery*, 1959].

Abyssal hills have been surveyed in a few places and thousands of profiles have been collected on echograms. As a consequence of IGY exploration, it is certain that abyssal hills have

a greater geographic extent than any other topographic form on Earth, but hardly anything is known of their origin.

Widespread terraces on the continental slope of the eastern United States appear to mark the outcrop of formations which can be traced by drilling and seismic techniques from land and confirmed by dredging [*Heezen* and others 1959]. Erosional terraces off Southern California show evidence of crustal warping toward the southwest which may have had a constant rate since Miocene time [*Emery*, 1958].

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Deep-Sea Sediments

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Introduction

The study of deep-sea sediments has been pursued with great energy over the last three years, following the realization that (a) deep-sea sediments are an important key to the history of the Pleistocene; and (b) a knowledge of Pleistocene history is fundamental to the understanding of current geophysical, geochemical, and biological processes, and their rates.

General

Heezen [1959] has written a brief but comprehensive review of the dynamic processes of deep-sea sedimentation. *Broecker* and others [1958] have shown that both the clay and the carbonate components in pelagic sediments were deposited faster during glacial ages than during interglacial ages. This conclusion, based on radiocarbon dating and geochemical analysis of an equatorial Atlantic core, probably holds true for the Atlantic and adjacent seas [*Ewing* and others, 1958], and possibly also for the Pacific and Indian Oceans. Rates of millimeters per 1000 yr in Pacific cores were determined by *Goldberg* and *Koide* [1958], using ionium. The ionium method of dating pelagic sediments was critically examined by *Volchok* and *Kulp*

[1957]. These authors conclude that the method may be applicable to cores collected from the deeper portions of the oceans, far from land.

Hurley [1958] determined the age of a sample of red clay 19.4 cm below the top of a core from the central Pacific, using both the ionium method and the A/K method. The ionium method gave an age about 280,000 years (age of deposition of the sediments) while the A/K method gave an age of about 80 million years (average age of the clay minerals). This indicates that the red clay analysed is largely allogenic.

Goldberg and *Arrhenius* [1958] conducted a detailed chemical and mineralogical analysis on 39 cores from the Pacific. The purpose of this study was geochemical rather than stratigraphic. Si, Na, K, and Ti were shown to occur in concentrations similar to those in igneous rocks. The Ba/Ti ratio was found to vary with latitude and reach a maximum under the equatorial zone of high organic productivity, suggesting that the Ba precipitation is some function of the organic activity in the euphotic zone. Comparison between the Mn concentration in Atlantic and Pacific pelagic sediments indicates that the average rate of sedimentation is lower in the Pacific, as expected. A geochemical balance calculation, based on Na, K, Ca, and Mn, sugests that pelagic clays represent 13% of the total amount of sediments produced during geologic time.

The diagenetic processes, leading to lithification of pelagic sediments, were the object of a detailed investigation by *Hamilton* [1959]. This author concluded that lithification of both clay and calcareous oozes should start between 150 and 700 m below the sediment surface, resulting in sediments capable of transmitting elastic compressional waves with velocities of 2 to 5 km/sec. If these sediments are considered, a better fit is obtained with geochemical estimates of the total amount of sediments produced in geologic time.

Evidence largely supplied by deep-sea cores was used by *Emiliani* and *Geiss* [1959] in a paper dealing with glaciations and their causes.

Special investigations

Atlantic Ocean and adjacent seas—Wangersky [1959] analyzed four Lamont cores, two from the equatorial Atlantic and two from the Caribbean. Ca, Mg, Fe, Ti, Mn, Si, and Al were determined. The total amount of $CaCO_3$, resulting from at least two component (foraminifera and coccoliths) appear to vary independently of paleotemperatures, but the two components show a respectively direct and inverse relationship to paleotemperature. The Al/SiO_2 ratio was found to vary around 0.32 in the upper portions of the cores, with the variations diminishing with the depth down the cores. Mg was found to be inversely related to paleotemperature and is predominant in the carbonate fraction (coccoliths) during glacial ages and in the clay fraction during interglacial ages. Mn was found to be inversely related to paleotemperature in one of the Caribbean cores. Evidence of extensive Mn migration was observed in the two Atlantic cores.

Emiliani [1958] published the paleotemperature record of the *Albatross* core 280 from the North Atlantic. This record correlates very well with similar records previously published and permitted the working out of a more detailed, generalized graph of the temperature variations during the last 300,000 years. A close correlation was noticed between these temperature variations and the climatic record of pollen profiles from continental areas. In addition, paleotemperature analysis of bentonic calcareous foraminifera from a suite of samples of the *Albatross* core 234 (Equatorial Atlantic) revealed that the bottom temperature of the Equatorial Atlantic varied from glacial minima of 0.5°C to an interglacial maximum of 4°C, and followed the trend of the temperature variation of the surface water.

Ericson [1959] showed that 7.2°C April isotherm of the North Atlantic coincides with the boundary between predominantly left-coiling populations of Globigerina pachyderma to the north and predominantly right-coiling populations to the south. Predominantly left-coiling populations were observed at various depths in cores from the southern province, suggesting that the 7.2°C April isotherm occupied a more southern position during glacial ages.

Shepard [1959] reconsidered the problem of the famous turbidity current which broke the cables south of the Newfoundland Grand Banks, following the 1929 earthquake. Maximum velocities of 55 and even 85 mi/hr had been calculated on the basis of the successive cable breaks. Shepard showed that the breaks occurred simul-

taneously over an area within 100 miles from the epicenter and that, outside this area, the successive breaks indicate a turbidity-current velocity of only 15 mi/hr.

Emiliani [1959] discussed the results of Yalkovsky's geochemical analysis of a Lamont core from the Caribbean.

Ewing and others [1958] published an important paper on the topography and sediments of the Gulf of Mexico. This area is characterized by wide continental shelves and by scarps across the continental slope. About 25% of the area is occupied by the Mississippi cone and about 6% by the abyssal plain. Cores from the lower region of the cone and the abyssal plain consist of a foraminifer lutite layer, 20–30 cm thick at the top, followed by at least 11 m of silty clay. C-14 dating showed that (a) the transition occurred 11,000 years ago; and (b) the rate of sedimentation of the silty clay is several times faster than that of the foraminiferal lutite (which is a few to several centimeters per 1000 years). Cores from knolls near the center of the abyssal plain yielded sections of foraminiferal lutite apparently reaching the glacial stage preceding the last interglacial. Average rates of sedimentation of several centimeters per 1000 years can be estimated for these cores.

Heezen and others [1959] showed that benthonic foraminifera ceased to exist on the bottom of the Cariaco Trench (Caribbean) about 11,000 years ago, following the rapid onset of anaerobic conditions. *Norin* [1958] published a very substantial work on the mineralogy of an *Albatross* core from the central Tyrrhenian Sea. Numerous volcanic ash and turbidity current layers are present in this core, complicating the stratigraphic picture. *Todd* [1958] published a comprehensive study of both pelagic and benthonic foraminifera in a number of *Albatross* cores from the western Mediterranean. The inferred climatic picture shows that the cores raised close to the Algerian coast are largely postglacial, while the cores from the central western Mediterranean and the Tyrrhenian sea reach the last glacial stage and sometimes the last interglacial stage. The sampling, at 50 cm stratigraphic intervals, may have been inadequate. *Parker* [1958] studied the benthonic and pelagic foraminifera in the *Albatross* cores from the eastern Mediterranean. These cores appear to represent longer stratigraphic intervals than the western Mediterranean cores. Most cores reach the Middle Pleistocene and satisfactory correlations were provided on the basis of the micropaleontological record. The climatic record furnished by the foraminifera of core 189 proved to be strikingly similar to the record obtained by oxygen isotopic analysis. Rates of sedimentation were calculated by correlation with the continental stages and using the old time estimates of Penck and Brückner, Kay, and Zeuner. These have been shown by C-14 to be off by a factor of two, so that the calculated rates of sedimentation are also off by a similar amount.

Ericson and *Wollin* [1959] and *Donn* and others [1959] reported the widespread occurrence of angular pebbles, shells, and shell fragments on the floor of the Arctic basin. The average age of the surface material (C-14 analysis of grab samples) is 9500 years. C-14 analysis of core samples gave discrepant results, probably because of heterogeneity of the material. Nevertheless, the top portion of the cores (0-20 cm) appeared to contain markedly less sand and angular fragments than underlying layers, a probable result of a marked decrease of iceberg activity in the Arctic ocean during the postglacial.

Pacific Ocean—Riedel [1957] published a preliminary, important work on the radiolaria in 12 *Albatross* cores from the Western Pacific, with remarks on the Cenozoic radiolarian stratigraphy. Extensive reworking of radiolarian shells was observed in the cores. *Bramlette* [1958] and *Riedel* and *Bramlette* [1959] stressed that coccoliths are important stratigraphic fossils because of widespread occurrence and relatively short time ranges of many species. The skeleta of Tertiary radiolaria are generally stronger than those of Pleistocene radiolaria. Tertiary sediments are not infrequently encountered in areas of the Pacific ocean, discomformably covered by Pleistocene sediments. The oldest pelagic sediments so far sampled are Eocene. These occurrences suggest that pelagic rates of sedimentation were much lower during the Tertiary than during the Pleistocene. *Hamilton* and *Rex* [1959] studied three Tertiary samples of phosphatized Globigerina-ooze from the flanks of Sylvania Guyot. The foraminifera were found to be of Lower Eocene age in one sample and of Miocene age in the other two. Erosion

of Sylvania seamount to a flat bank in Late Cretaceous or Early Eocene time is indicated. Rapid subsidence then prevented coral growth and the establishment of an atoll, as it happened to the adjoining Bikini structure.

Bramlette and others [1959] studied 11 cores collected at depths from 1400 to 1800 m on the SW flank of the Eniwetok Atoll. A thin veneer of Pleistocene coarse sediments (with pelagic foraminifera and coccoliths) of Pliocene age, suggesting a drastic change in the sedimentary environment from Pliocene to Pleistocene. *Worzel* [1959] discovered a huge ash layer off the west coast of Central and South America, ranging in thickness from a few cm. to 30 cm. and occurring from the surface down to 40 m below the sediment surface. *Ewing* and others [1959] estimated the age of the ash layer at about 100,000 years and suggested that it may be wider than hitherto discovered and may provide a good time reference level.

Gorsline and *Emery* [1959] studied the turbidity current deposits in two basins off the coast of southern California. These basins contain alternations of deeper and shallower sediments, similar to those occurring in the basins which are now part of the southern California mainland.

Antarctic Oceans—Thomas [1959] studied a 90-cm long core from the Antarctic Ocean and found several alternations of coarse and fine grained glacial marine sediments. Correlation with cores previously studied by Hough suggested that the core reaches back in time to include the last interglacial age.

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VOLCANOLOGY
(*including* Geochemistry and Petrology)

LEASON H. ADAMS, *Editor*

Volcanological Observations

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The U. S. Geological Survey has established a geochemical laboratory at its Hawaiian Volcano Observatory on the rim of Kilauea (Hawaii). The observatory is staffed by seismologists, geophysicists, and geochemists, and is equipped for optical spectroscopy, mass spectroscopy of gases, chemical analysis, seismology, and precision leveling. The recent eruption, beginning with violent activity of Kilauea Iki volcano from November 14 to December 20, 1959, followed by the eruption 20 miles eastward along the rift zone, at Kapoho, from January 13 to February 19, 1960, and collapse of the floor of Halemaumau Pit on February 7 and March 11, yielded intensive observations through a complete cycle of activity.

The staff, headed by Kiguma J. Murata, has been engaged in a round-the-clock program of gas sampling, daily analysis of the changing lavas, and geophysical and geological observations during the eruption. Seismographic observations, and measurements of ground tilt around the summit with a newly developed precision liquid leveling device, gave reliable warnings of impending outbursts.

Donald E. White has attempted to correlate the chemical composition of volcanic and other thermal waters with their geologic history. Harmon Craig and Donald White are using the deuterium and heavy oxygen (O^{18}) content of thermal waters as natural tracers as an independent approach to determine origin and history.

Experimental Petrology

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During the past three years there have been very significant contributions to experimental petrology in this country. First, in the area of anhydrous silicates there has been a report [*Smith* and *Sahama*, 1957; *Tuttle* and *Smith*, 1958] on the system nephelinekalsilite relating to the common feldspathoids. There has been significant progress in the relations [*MacCheney* and *Muan*, 1959] between oxides of iron and titania. In the field of rock-forming pyroxenes [*Boyd* and *Schairer*, 1957ab; *Schairer*, *Boyd*, and *Eugster*, 1956] with and without feldspars [*Schairer* and *Morimoto*, 1958] there has been notable progress, and in the field of

Mn-bearing pyroxenes and olivines important relations have been reported [*Glasser*, 1958; *Glasser* and *Osborn*, 1957]. Data are now available on the anhydrous system grossularite-pyrope [*Chinner* and *Schairer*, 1959] at one atmosphere pressure. Data [*Turnock* and *Eugster*, 1958, 1959] on the spinels magnetite-hereynite and magnetite-hematite-corundum have been reported, and a revision of the system Al_2O_3–SiO_2 has been made [*Aramaki* and *Roy*, 1959].

Notable advances have been made in hydrothermal studies. Outstanding are the reports on feldspars in the systems albite-anerthite-water, albite-orthoclase-water and albite-orthoclase-anorthite-water [*Yoder* and others, 1957], and on anorthite-silica-water [*Stewart*, 1958]. The synthesis of zoisite between 1000 and 5000 bars has been reported [*Rapp*, 1957]. Data on alakli-amphiboles [*Ernst*, 1958, 1959] and the rock-forming biotites [*Wones*, 1958, 1959; *Eugster* and *Wones*, 1958; *Wones* and *Eugster*, 1959] have been noteworthy. Even in the area of difficult complex hydrous minerals such as iron chlorite, 'significant data have been recorded [*Turnock*, 1958]. The stability relations of Mg-cordierite in the system MgO–Al_2O_3–SiO_2–H_2O have been delineated [*Schreyer* and *Yoder*, 1958, 1959]. Data on the relations in a portion of the system K_2O–Al_2O_3–SiO_2–H_2O have been given [*Hemley*, 1958]. There has been some progress in the difficult relations in the systems CaO–Al_2O_3–SiO_2–H_2O [*Roy* and *Roy*, 1957; *Koizumi* and *Roy*, 1957] and in Al_2O_3–SiO_2–H_2O [*Aramaki* and *Roy*, 1958] and on the melting temperatures of shales [*Wyllie* and *Tuttle*, 1958] under hydrothermal conditions. Additional data on the upper three-phase region in SiO_2–H_2O have been reported [*Kennedy* and others, 1959].

For the first time we have quantitative information on systems with more than one volatile component. General relations on the effect of volatile materials on melting temperatures of silicates have been discussed [*Wyllie* and *Tuttle*, 1957] and specific data on the joins calcite–H_2O [*Tuttle* and *Wyllie*, 1958] and calcite-porlandite [*Wyllie* and *Tuttle*, 1959] in the system CaO–CO_2–H_2O have been given. Preliminary data [*Tuttle* and *Wyllie*, 1957] are available on albite–H_2O–HF and 'granite'–H_2O–HF.

Particularly during the past two years, noteworthy advances in our knowledge of sulfide and arsenide systems, that are fundamental to an interpretation of ore minerals, have been made in experimental petrology. These include data on solidus relations in Cu–Fe–S between 400° and 800° C [*Roseboom* and *Kullerud*, 1958] on the systems Fe–As–S [*Clark*, 1958] Ag_2S–Bi_2S–PbS [*Van Hook*, 1958] Cu_2S–Cu_2FeS_2 [*Kullerud* and *Roseboom*, 1958], Ni–S [*Kullerud* and *Yund*, 1959] Ni–As–S [*Yund*, 1959], FeS_2–NiS_2 [*Clark, L. A.*, and *Kullerud*, 1959], the iron-rich portion of Fe–Ni–S [*Clark, S. P.*, and *Kullerud*, 1959] and solubilities in the region between 25° and 180° C at 100 to 600 p. s. i. in the system ZnS–H_2S–H_2O [*Barnes*, 1959]. A perusal of the references will show that the Geophysical Laboratory, Carnegie Institution of Washington, and the School of Mineral Industries at the Pennsylvania State University have been especially active in the field of experimental petrology.

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Phase Relations of Some Rocks and Minerals at High Temperatures and High Pressures

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Prior to the last war only two laboratories in the United States were actively engaged in research in the field of very high pressures. These were the laboratory of P. W. Bridgman and his colleagues at Harvard University and the laboratory of L. H. Adams and colleagues at the Carnegie Institution of Washington, Washington, D. C. Pressures to 10,000 atmos and beyond require special materials and special techniques, which more or less serve as a sharp cutoff between the high pressure field and the field of medium to low pressures. Laboratories

currently engaged in research at very high pressures are those of Francis Birch at Harvard University, of F. R. Boyd and H. Yoder at the Geophysical Laboratory, Carnegie Institution of Washington, of Rustum Roy and his colleagues at the Pennsylvania State University, of Julian Goldsmith at the University of Chicago, of D. T. Griggs and G. C. Kennedy at the Institute of Geophysics, University of California, and of Tracy Hall at Brigham Young University, Utah. In addition to these research laboratories, advances have been made in the industrial laboratories of the General Electric Company, and L. Coes has stimulated a very large amount of work by his early results on mineralogical transitions at the laboratories of the Norton Company in Worcester, Massachusetts.

Apparatus—The major difficulty with the earlier designs of high-pressure, high-temperature apparatus is that the entire furnace assembly must be extracted after each run in order to fetch out the sample and replace it with a new run. This is a very laborious and time consuming procedure, and pressure packings, frequently disturbed, are troublesome. Two permutations involving a system where little other than the sample is extracted from the furnace with all major packing left in place, have been built by Kennedy and by Griggs. Griggs' design involves a Carboloy rod sealed into the opening by a controlled clearance packing of the type of the Newhall-Johnson type. This apparatus is extremely rapid in operation, and there is practically no lost time in interchanging the samples. As many as 15 runs in a single day have been made with this apparatus and scores of runs in sequence have been made without lost time for overhauling packings and repair of parts.

The apparatus designed by Kennedy involves a somewhat different feature. A furnace inside the pressure container is wound on a thick-walled platinum tube, and the sample is carried on the end of a platinum rod into the thick-walled tube, analogous to Tuttle's cold-seal apparatus [*Tuttle*, 1949]. In this apparatus the sample is not placed in a separate sealed capsule but is acted upon directly by water or any desired mixture of gases. The pressure inside the platinum tube is exactly balanced, via a mercury-filled U tube or silicon-filled U tube, with the pressure outside the thick-walled platinum tubing.

Robertson and others [1957] have described a multiple-piece gas apparatus, modified from Bridgman, capable of pressures up to 25,000 atmos. For higher pressures, solid-pressure transmitting media with radically different designs are required. Perhaps the most spectacular advance has been made by Tracy Hall in designs for solid-pressure apparatus, as illustrated by the device constructed at the General Electric Company for achieving pressures up to 180,000 atmos and temperatures as high as 2000°C and found practical for the production of synthetic diamonds. Tracy Hall has developed another high-pressure device which achieves pressures and temperatures almost comparable to that of the earlier apparatus. In this device four tetrahedral pistons are simultaneously advanced on a tetrahedron of pyrophyllite containing the sample. Provision is made for an internal furnace. Pressures of 100,000 atmos at temperatures of 1000°C can be readily obtained with this gear [*Hall*, 1958].

Boyd and *England* [1958] have developed some effective high-pressure apparatus with certain novel design features. This gear has been used successfully to 100,000 atmos and 1500°C, and the design is probably capable of even higher pressures and temperatures. *Griggs* and *Kennedy* [1956] describe a simple two-piston high-pressure device. This was a modification of earlier Bridgman apparatus equipped with an external heater. This device is simple in construction and operation and has proved useful in mineralogical phase work. Temperatures of 1000°C at pressures of 20 kb are obtainable, with considerably higher pressures at lower temperatures.

Results—Four general categories of results of work at high pressures have recently appeared. These results are melting points of minerals under high confining pressures, melting curves for minerals under high water pressure, vapor pressures of hydrous-anhydrous mineral assemblages at high water pressures, and equilibrium curves for solid-solid phase changes at high temperatures and pressures.

Confining pressure increases the melting temperatures of minerals, but high water pressure decreases the melting temperature of minerals by virtue of the solubility of water in the melt.

A summary of the available information on melting curves under high water pressures has been published recently by *Yoder* [1958].

In addition to these melting-point curves for individual minerals, data to 4 kb H_2O pressure for the solidus curve are available for granite [*Tuttle* and *Bowen*, 1958]. Unfortunately, detailed data on the liquidus curve for granite are not available. However, some results from the Tuttle-Bowen work indicate the liquidus for granite lies only 30°–40° above the solidus.

The vapor pressures of a number of hydrous-anhydrous mineral equilibrium assemblages have been determined. These are shown in Figure 1. Data are available from gypsum = anhydrate + water, gypsum = hemihydrate + water, and hemihydrate = anhydrate + water (Kennedy and Lyon, unpublished). Data for aluminum oxide and water are available. The curves shown are those for gibbsite = diaspore + water and diaspore = corundum + water (Kennedy, in press, *Am. J. Sci.*). Composite curves are given also for the boundary of kaolin = sillimanite + pyrophyllite + water; kaolin = kyanite + pyrophyllite + water, pyrophyllite = sillimanite + quartz + water, pyrophyllite = kyanite + quartz + water; and pyrophyllite = kyanite + coesite + water (Kennedy, unpublished).

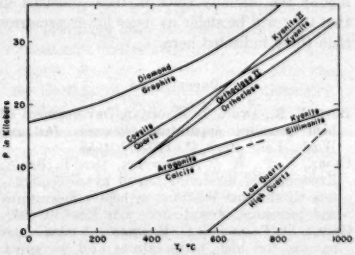

FIG. 1—H_2O vapor pressures of some hydrous minerals

A large number of solid-solid phase transitions have been investigated at high temperatures and pressures. The kyanite-sillimanite boundary has been studied experimentally at high temperatures by *Clark* and others [1957]. The agreement with earlier data is excellent. This and other equilibrium relations are shown in Figure 2. The graphite-diamond curve is drawn from the various theoretical studies from thermochemical data by Goranson, Liljeblad, Berman, Simon, and MacDonald, as confirmed by recent experimental work at General Electric Company.

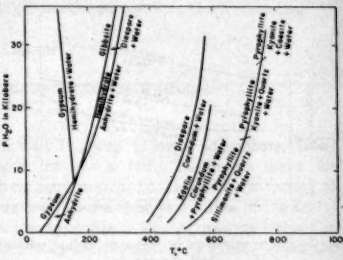

FIG. 2—Some solid-solid phase changes

Several other important phase changes in common minerals are known to exist but have not yet been studied in sufficient detail. *Ringwood* [1958] reports a transition in fayalite from orthorhombic to spinel structure taking place at 400°C and 45 kb. Unfortunately the slope of the phase boundary is not known. Phase changes have been sought to 50 kb and 500°C but not found in dolomite and enstatite.

In addition to simple solid-solid phase transitions much more complex changes at high pressures take place in certain systems, as for example in the assemblages grossularite and hydrogrossularite, and anorthite and wollastonite (Pistorius and Kennedy, unpublished). The amount of quartz involved in the reaction changes regularly as temperature and pressure change.

Further interesting examples of pressure exsolution of a dense phase are found in the system involving nepheline ($Na_2O \cdot Al_2O_3 \cdot 2SiO_2$), albite ($Na_2O \cdot Al_2O_3 \cdot 6SiO_2$), and jadeite ($Na_2O \cdot Al_2O_3 \cdot 4SiO_2$). In the 'wet' system where pressure is pressure of H_2O (Kennedy, unpublished), melting relations mask the reaction: nepheline + albite = 2 jadeite. In the dry system, melting relations do not mask the phase changes involving nepheline, albite, and jadeite. Relations between these phases, as worked out in the piston-anvil device, are shown in Figure 3 (Kennedy, unpublished).

Nepheline and albite are mutually soluble at

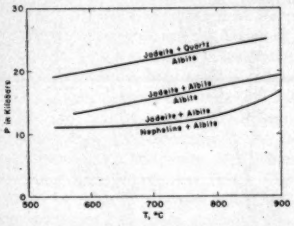

FIG. 3—Phase relations between nepheline, albite, and jadeite

high temperatures and high pressures. Nepheline, saturated with albite and thus containing more silica than stoichiometric nepheline, undergoes a phase change to silica-deficient jadeite with albite remaining unchanged. Albite dissolves in the jadeite as pressure is raised. Pure albite exsolves jade along the boundary, as indicated in Figure 3, and, at a somewhat high pressure, breaks down completely to jadeite plus quartz.

Pressure solid-solution relations have been established for the system $Al_2O_3 \cdot SiO_2 \cdot H_2O$ (Kennedy, unpublished). These relations, determined by the breakdown of kaolinite at high temperature and pressure, show the stability fields of various phases in the system. The field of andalusite was not determined. Of particular interest is the solid-solution relationship shown between mullite ($3Al_2O_3 \cdot 2SiO_2$) and sillimanite ($Al_2O_3 \cdot SiO_2$). Pure mullite was synthesized by breaking down kaolin at very low pressures. At 1 kb H_2O pressure, half-breed compounds of approximate composition of 50 sillimanite 50 mullite are formed. Only at pressures of approximately 13 kb, along the pyrophyllite boundary, were compositions of 90 sillimanite 10 mullite formed, and pure 100% sillimanites were formed only at still higher pressures. These relationships are most puzzling and seem to be at odds with the compositions of naturally occurring minerals.

Concluding remarks—It is very difficult to achieve equilibrium between condensed silicate phases, particularly in the low temperature and pressure region. Many of the diagrams presented in the papers to which reference is made here are 'preliminary' in the sense that conclusive evidences of equilibrium have not been obtained in many cases, that is, the reverse reactions at the field boundaries have not always been demonstrated. The general relationships are believed to be correct, but it is certain that refined work by different experimental techniques may change the field boundaries somewhat.

The most startling thing from the geological point of view is that high-pressure polymorphism of common silicate phases known at the surface of the Earth appears to be the rule rather than the exception. In general, however, the depth at which common polymorphs are formed appears to be greater than current geological thinking would admit. Of particular pertinence are the considerable depths in the Earth's crust needed to form the dense phases grossularite, zoisite, lawsonite, kyanite, and jadeite. It must be remembered that 'impurities' in the crystal, such as iron in grossularite, zoisite, and jadeite, will probably drastically modify the stability fields of these minerals so that they will be stable at much lower pressures than those indicated here.

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Geochronology

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The triennium 1957–60 has seen the work in absolute age determinations of rocks proceed at an ever growing rate. The work in the United States, coupled with that of our colleagues from Canada, has provided a steadily increasing amount of reliable data on North America in particular, and, more generally, South America, the Fenn Scandian Shield and recently the area around the Red Sea has also been studied. In addition to the work which has continued at the California Institute of Technology, the University of California at Berkeley, Columbia University, the Carnegie Institution of Washington, the Massachusetts Institute of Technology, University of Minnesota, and the U. S. Geological Survey; a new laboratory has been established at the University of Arizona. The flow of data from these laboratories is such that this work now contributes from 1/4 to 1/3 of the papers presented at the Annual Meetings of the Section of Volcanology, Geochemistry, and Petrology of the American Geophysical Union.

Ages of minerals in sedimentary rocks have been studied at M.I.T. [*Hurley* and others, 1959], University of California at Berkeley [*Lipson*, 1958] and the University of Chicago [*Wasserburg* and others, 1956], and this work has been extended to the study of minerals found in bentonites interbedded with sedimentary rocks at the Geological Survey [*Faul* and *Thomas*, 1959] and the Shell Laboratories [*Edwards* and others, 1956]. The interpretation of the ages found in each of these studies is still the subject of considerable investigation, but promise is shown in that the relative ages obtained are nearly always in the right order. The work on the sedimentary rocks themselves, together with that on igneous rocks with known relationship to sedimentary formations, has provided many additional points on the fossil time scale, but until the results are further verified it is difficult to properly evaluate the status of this interesting geochronological problem as yet.

The ages of tektites has also been studied. The M.I.T. group [*Pinson* and others, 1958] found too low a ratio, Rb/Sr, to make the Rb-Sr ages meaningful. *Reynolds* [in press] at Berkeley found a close correlation of the age of tektites with that of the sedimentary horizon in which they are found. *Tilton* [1958] found the lead in the tektites he analyzed to be normal modern lead, a fact which makes it difficult to make them of extra-terrestrial material.

The investigations of the Precambrian areas of the world have been progressing steadily at the Carnegie Institution of Washington [*Aldrich* and others, 1959], the University of Minnesota [*Goldich* and others, 1957, 1960], the California Institute of Technology [*Wasserburg* and others, 1959], the Massachusetts Institute of Technology [*Hurley* and others, 1959] and Columbia University [*Gast* and others, 1958; *Eckelmann* and *Kulp*, 1957]. In most instances the data are still quite fragmentary, but patterns are nonetheless emerging which will provide a basis for discussion of theories of continent formation, simultaneity of orogenic events on different continents and the correlation of Precambrian sedimentary formations themselves.

All of these conclusions are subject to the problems associated with mineral age determinations shown by *Tilton* and others [1958] in the Baltimore area, by *Wetherill* [1957] in the Sudbury area, by *Wasserburg*, and others [1959] in Death Valley, and by Aldrich and others [1959] in the upper peninsula of northern Michigan. Most of these regions were known to have been metamorphosed. The complexity of the results is such that very great caution must be taken in the interpretation of any results unless the geological evidence for metamorphism is completely negative.

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Changes in Wisconsin Glacial Stage Chronology by C^{14} Dating

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Progress has been extremely rapid in the field of Pleistocene chronology in the past few years. This is due to advances in C^{14} dating and to the development of other dating methods. With the modification of the original counting of C^{14} using the solid carbon method, to the present gas counting techniques, more and more laboratories were initiated. Today, more than 35 laboratories throughout the world are turning out dates for geologists, archeologists, botanists, and geochemists. The new techniques, including gas counting with a variety of gases, scintillation counting, isotopic enrichment, and ionium-uranium decay methods, have extended the range of absolute dating to include the entire last glacial stage. The flood of dated samples issuing from the laboratories has required workers in the field of Pleistocene chronology to make changes in the previously accepted models of glacial advances and retreats. This is not to say that the dates alone have made revisions necessary, but that the dates have inspired additional stratigraphic studies which in turn unearthed new information.

For many years, the accepted chronology of the last glacial stage for the continental glaciers of the United States consisted of the Wisconsin stage, divided into five substages. These were the Mankato, Cary, Tazewell, Iowan, and Farmdale, from youngest to oldest. The time since the last substage was computed by waterfall recession to be approximately 25,000 years. Using a weathering ratio of a few feet of weathering on the top till per 25,000 years, a very rough estimate of 120,000 years was made for the length of the Wisconsin stage.

Some of the first samples to be dated for geologists came from the buried forest beds at Two Creeks, Wisconsin. The dates of approximately 11,400 years gave the time since the last ice advance into the Great Lakes region. Later, dating of the Farmdale at approximately 25,000 years made the Wisconsin stage seem considerably younger than previously estimated. But the finding of tills and loesses with included wood having ages of greater than 40,000 years, and still within the last glacial stage, again expanded the time scale. The Iowan till was

found to be in this older category and so was placed below the Farmdale substage instead of in a younger or stratigraphically higher position.

Attempts to date absolutely the European Eemian interval, which is believed to be equivalent to the Sangamon interglacial stage preceding the last glacial, were unsuccessful, even with the use of isotopic enrichment on the samples. Thus the base of the Wisconsin stage is older than 70,000 years, with estimates ranging up to 100,000 years.

The type Mankato till was dated at approximately 12,000 years, making it older than the Valders till of Thwaites at Two Creeks; and actually placing it into the Cary substage range of ages.

Because of the difficulty in finding any type of break between the Cary-age and the Tazewell-age deposits in many places, some workers have abandoned the division of the two entirely, grouping them together.

To summarize the present state of chronology of the Wisconsin stage, the last advance into the Great Lakes area culminated approximately 11,000 years ago, and the beginning of the entire stage occurred sometime between 70,000 and 100,000 years ago. Between 70,000 or 100,000 years ago and approximately 28,000 years ago, there was either one very long substage, or several shorter ones. The Iowan age till of Iowa is included here. From 28,000 to 22,000 years ago, Farmdale substage deposits were laid down. Some workers believe that from 22,000 to 12,000 years ago, only one substage occurred, encompassing deposits known previously as Iowan loess of Illinois, Tazewell drift, Cary drift, and Mankato drift. The Two Creeks substage was a short pause during the later advances of the Wisconsin stage, and was terminated by the Valders substage with the readvance of the ice approximately 11,000 years ago. The Valders substage ended with the retreat of ice into the Hudson Bay area and is arbitrarily terminated at approximately 8,500 years ago.

Cosmic-Ray Effects in Meteorites*

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The study of the effects of cosmic-ray bombardment of meteorites has included the measurement of the radioactive and stable isotopes produced, as well as attempts to understand the phenomena in terms of reactions produced in the laboratory by the bombardment of targets by high-energy proton beams.

At the Brookhaven National Laboratory, studies of various kinds have been under way. The work on stable isotopes has been centered in the laboratory of Oliver Schaeffer, who has a high-sensitivity mass spectrometer suitable for the quantitative analysis of minute amounts of rare gases. *Schaeffer* and *Zähringer* [1959] have measured production cross sections for the helium and argon isotopes generated in iron as the result of bombardment by protons having energies of 0.16, 0.43, and 3.0 Bev. They believe that at 3 Bev the production ratio He^3/T may be 2.4; if so, the exposure ages of meteorites by the He^3-T method may be lower by a factor of three than previously supposed. From the argon cross sections they conclude that a determination of Cl^{36} and A^{36} should provide a reliable method of measuring exposure ages of meteorites. In a further study (in publication) they have examined the helium, neon, and argon isotopes in seven iron meteorites having varying helium contents. They believe that the He^3/He^4, He^3/Ne^{21}, and He^3/Ar^{36} ratios in a sample may make it possible to determine the depth

* This summary is not intended to be a complete bibliography but merely to indicate the nature of some of the more important work done in the field in the United States of America in the past few years.

of the sample in the original meteoroid. Schaeffer and his colleagues are investigating other meteorites, both stone and iron—as well as targets—in studies which promise to shed considerable light on the entire problem of interaction of cosmic rays with meteorites and radiation ages of meteorites.

Fireman, working at the Smithsonian Astrophysical Laboratory, Cambridge, Massachusetts, and in close cooperation with the Brookhaven group, has applied low level counting techniques to problems relating to meteorites. Thus *Fireman* and *Zahringer* [1957] have studied the depth variation of T and Ar^{37} produced in iron by the bombardment of protons in the multi-Mev and Bev range. By using neutron activation techniques, *Fireman* [1959] has measured the He^3 concentration in the cross sections of several iron meteorites. In order to measure radiation ages of meteorites he has looked for low-level radiation due to various radioactive isotopes which are generated by cosmic ray bombardment and has shown that the Sikhote-Alin meteorite [*Fireman*, 1958] contains a measurable amount of A^{39}. He proposes that the ratio of A^{39} to the A^{39} decay rate may be used to determine a radiation age in this meteorite.

Working at the University of Chicago, *Begemann* and others [1957]; *Begemann* and others [1959] have determined 'radiation ages' of recently fallen meteorites from the ratio of He^3 to tritium activity. In the stone meteorite, Norton County [*Begemann* and others, 1957], this method gave an age lying between 200 and 300 million years. On the other hand, the A^{40}–K^{40} age for this meteorite is near 4400 million years. This large discrepancy can only be explained by the assumption that the intensity of radiation has changed drastically in the past 4400 million years or that the He^3–H^3 age defines a time when a much larger body broke up and produced this meteorite. It can be seen that the determination of 'age' by this method (also using other elements where a radioactive nuclide and its decay product can be measured) promises to provide very interesting data on meteorites and the history of cosmic radiation.

Ehmann and *Kohman* [1958] at the Carnegie Institute of Technology have detected Al^{26} and Be^{10} in stone and iron meteorites. They believe these to be cosmic-ray induced. *Anders* [in press], at the University of Chicago, obtained a gratifying verification of the Al^{26} level in the Plainview Chondrite—one previously studied by Ehmann and Kohman. *Honda* [1959], working at the Scripps Institution of Oceanography, measured the specific activity of the potassium extracted from several iron meteorites and found this to be measurably above that of normal potassium. An isotopic analysis of the potassium showed that the K^{40}/K^{39} and K^{40}/K^{41} ratios were indeed higher than that of normal potassium. This study, confirming the work of *Voshage* and *Hintenberger* [1959], gives hope that the ratio of cosmic-ray produced A^{38} to K^{40} may be useful for radiation age measurements or for arriving at conclusions as to the constancy of cosmic-ray intensity over long periods of time. That this hope may be realized is not certain; traces of ordinary potassium in the sample or introduced in handling, together with the problem of atmospheric A^{38} contamination in the gas handling system or mass spectrometer, make this a most formidable problem.

Van Dilla, *Arnold*, and *Anderson* [in press], working at the Los Alamos Scientific Laboratory and employing low-level gamma-ray spectrometry, have perfected a method for measuring low-level natural and cosmic-ray induced radioactivities in meteorites without destruction of the specimen. Since no chemical processing or reagents are employed, the method, when applicable, is free from contamination problems. They report K^{40} and Al^{26} activities in several chondrites and in an achondrite. These results are in essential agreement with previous chemical measurements. An interesting feature of the work was the detection of activity from Co^{60} (half-life 5.2 years) in a recent iron fall but none in old iron falls. If, as seems likely, this can only be produced by reactions involving thermal neutrons, it should be found in only those meteorites whose pre-atmospheric masses were sufficiently great to produce thermalization of neutrons. This difference in mechanism of production from that of normal spallation should provide an independent check of size of the object in which irradiation took place.

The verification of the presence in meteorites of cosmic-ray produced radioactive isotopes having a wide range of half-lives; namely T, 12.3 years to K^{40}, 1.3×10^9 years, suggests that

age measurements based on their abundances may be made on meteorites which have fallen at various times and that deductions relating to the constancy of cosmic rays over long periods of time may be possible.

In the mass spectroscopic laboratory at the University of Minnesota, *Hoffman* and *Nier* [1957, 1959, 1960] have studied the concentrations of He^3 and He^4 as a function of position in a number of iron meteorites. Contours of constant He^3 and constant He^4 concentration could be drawn. Through assumption of a production model for these isotopes, deductions were made as to the preatmospheric size and radiation ages of the objects. *Bieri* [1958] measured the neon and argon isotopes generated in a sample of Carbo and also measured the abundances of the helium, neon and argon isotopes generated in a copper target as a result of bombardment by 6 Bev protons. *Signer* and *Nier* [1960] have studied the variation with depth of the He, Ne, and Ar isotopes generated in the iron meteorite Grant previously examined for He alone [*Hoffman* and *Nier*, 1957, 1959, 1960]. Further, they have measured the rare-gas isotopes generated in copper and stainless-steel targets as a result of 6 Bev proton bombardment. Attempts are being made to formulate the results into a consistent picture.

At the University of California, Reynolds and his colleagues have applied the sensitive high-vacuum mass spectrometer developed for rare gas analyses to a number of problems relating to meteorites. In a study of the stone meteorite Nuevo Laredo [*Reynolds* and *Lipson*, 1957] the absolute amounts of each of the isotopes of helium, neon, argon, and xenon were found.

Several attempts have been made to observe cosmic-ray induced nuclides in tektites. *Ehmann* and *Kohman* [1958] reported traces of Al^{26} and Be^{10} in australites and also in Libyan Desert silica glass, suggesting that such objects are of extra-terrestrial origin. *Reynolds* [in press] searched for rare-gas nuclides, particularly He^3 and Ne^{21}, which might be cosmogenically induced. It was concluded that the diffusion rate of helium in tektites is so great that one should not expect to find He^3. Likewise, no Ne^{21} was detected, and limits were placed on the maximum 'flight time' since the last melting of each of the tektites studied. Thus this mass spectroscopic work neither supports nor refutes the postulate of extra-terrestrial origin of tektites.

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Abundance and Distribution of Elements

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During the past three years, investigations in these fields continued in North America at an accelerated pace. Two major works, revisions of Clarke's *Data of Geochemistry* and of Washington's compilation of analyses of igneous rocks, are well under way at the U. S. Geological Survey. From the latter revision have come four more bibliographies of rock analyses, *Hooker* [1957, 1958, 1959], and *Woodland* [1959].

A highly condensed review of data on abundances in all types of rocks is included in the table by *Green* [1959], which also has a comprehensive bibliography. Problems in the estimation of abundances are discussed by *Fleischer* and *Chao* [1959] and *Ahrens* and *Fleischer* [1960] give a compilation of determinations of minor elements in the rocks G-1 and W-1, which have been used as standards in many laboratories. *Jizba* [1959] discusses the statistical theory of frequency distribution of elements, and *Reed* [1959] the use of activation analysis.

Reviews of the cosmic abundances of the elements were published by *Suess* and *Urey* [1956] and by *Cameron* [1959a] and the status of theories on the synthesis of the elements in stars was reviewed by *Burbidge* and others [1957], *Urey* [1957], *Burbidge* and *Burbidge* [1958], and *Cameron* [1959b]. Many new determinations of trace elements in meteorites have been published, especially at Argonne National Laboratory and the California Institute of Technology: *Bates* and others [1958, 1959] (Th); *Cohen* [1959] (Ge, tektites); *Ehmann* and *Huizenga* [1959] (Bi, Tl, Hg); *Friedman* [1958] (U in tektites); *Gordon* and others [1957] (Cs); *Hamaguchi* and others [1957] (Ba, U); *Lovering* and others [1957] and *Nichiporuk* [1958] (Co, Cr, Cu, Ga, Ge, Ni); *Onishi* and *Sandell* [1957] (Sn); *Reed* and others [1958] (U); *Reed* and others [1959] (Bi, Pb, Tl, U).

Donahue [1959] has discussed the origin of sodium and lithium in the atmosphere.

Reviews of the geochemistry or phases of the geochemistry of several elements have appeared: *Adams, Osmond,* and *Rogers* [1959] (U, Th); *Fischer* [1959] (U, V), *Fleischer* [1959] (Re); *Frondel* [1958a] (Th, U); *Frondel* [1957] (Zr); *Shaw* [1957] (Ga, In, Tl); *U. S. Public Health Service* [1959] (F in water supplies); *Williamson* [1958] (V); *Williamson* and *Burgin* [1958, 1959] (Nb, Ta, rare earths) and *Young* [1957] (Co). Bibliographies on uranium and thorium include those of *Cooper* [1958], *Curtis* [1957, 1958], *Fix* [1958], *Jones* [1958], *Kehn* [1957], and *Melin* [1957], and *Soister* and *Conklin* [1959]. A bibliography on selenium also appeared [*Luttrell,* 1959].

New determinations of the geochemistry of specific elements in many types of rocks include those by *Carr* and *Turekian* [1959] (Co); *Cohen* [1959] (Ge); *El Wardani* [1957] (Ge); *Frondel* [1958b] (Sr); *Horstmann* [1957] (Cs, Li, Rb); *Levine* and *Grimaldi* [1958] (Th); *Merrill* and others [1958] (Be); *Murata* and others [1957, 1959] (rare earths); and *Warner* and others [1959] (Be). *Mrose* and *Wappner* [1959] discovered that scandium is a major constituent of two minerals previously thought to be aluminum phosphates.

The composition of igneous rocks was discussed by *Green* and *Poldervaart* [1958], and *Hurley* [1957] has considered the possible composition of the Earth's mantle as deduced from data on potassium, uranium, and thorium. Data on zirconium in igneous rocks have been reviewed by *Chao* and *Fleischer* [1959]. New data on specific minor elements in igneous rocks include those of *Davidson* and *Powers* [1959] (Se); *Earley* [1958] (Cl); *Hurley* and *Fairbairn* [1957] (Th, U); *Larsen* and *Gottfried* [1960] and *Larsen, Gottfried,* and *Malloy* [1958] (U, Th); *Siroonian* and others [1959] (Li); *Slawson* and *Nackowski* [1959] (Pb in feldspars of quartz monzonites); *Smith* and others [1957] (Th, U); *Storm* and *Holland* [1957] (Ni); and *Whitfield* and others [1959] (Th, U).

Spectrographic analyses for 10 to 20 elements have been published for many igneous rocks: *Cornwall* and *Rose* [1957]; *Engel* [1959];

Friedman [1957]; *Hamilton* [1959]; *Herz* and *Dutra* [1958]; *Lovering* [1957]; *Rogers* [1958]; *Rose* [1959]; *Snyder* [1959]; *Sun* and *Baldwin* [1958], and *Turekian* [1958a].

Similar data on trace elements in metamorphic rocks have been published by *Barnes* [1959], *Engel* and *Engel* [1958], and by *Wilcox* and *Poldervaart* [1958]. New determinations of the distribution of trace elements among coexisting phases have been made by *Devore* [1957], *Engel* and *Engel* [1958], and *Kretz* [1959].

New determinations of many minor elements have been published for limestones by *Ostrom* [1957] and by *Degens* and others [1957, 1958]. The composition of sandstones has been reviewed by *Middleton* [1959] and new data on the minor elements published by *Newman* and *Elston* [1959] and by *Shoemaker* and others [1959]. Many minor elements have been determined for argillites by *Shaw* [1956], *Macpherson* [1958], and by *Pettijohn* and *Bastron* [1959]. Similar data on shales have been published by *Bates* and *Strahl* [1958], *Strahl* [1959], and *Degens* and others [1957, 1958]; the latter suggest that the contents of B, Ga, and Rb serve to distinguish marine from nonmarine shales. The minor elements of marine sediments have been studied extensively by *Goldberg* and *Arrhenius* [1958] and by *Arrhenius* and *Bramlette* [1957]. The relative mobility of the major elements during weathering has been determined by *Anderson* and *Hawkes* [1958]; data on the fate of minor elements during weathering have been obtained by *Short* [1958] and by *Engle* and *Sharp* [1958]. Mechanisms for the separation of manganese from iron have been discussed by *Krauskopf* [1957].

Determinations of specific elements in sedimentary rocks have been made by *Adams, Richardson,* and *Templeton* [1958] (Th, U); *Adams* and *Weaver* [1958] (Th, U); *Altschuler* and others [1958]; *Clark* and *Altschuler* [1958] (U, phosphorites); *El Wardeni* [1958] (Ge, marine sediments); *Murray* and *Adams* [1958] (K, Th, U, sandstones); *Pliler* and *Adams* (1959a, 1959b] (Th, U); *Sheldon* [1959] (U, phosphorites and shales); *Sternberg, Fischer,* and *Holland* [1959] (Sr in limestones); *Tatsumoto* and *Goldberg* [1959] (U, marine sediments); *Turekian* [1958b] (Ni, marine sediments); *Welby* [1958] (Cs, Li, Rb, marine sediments); and *White* [1957] (Zn, soils).

Considerable work has been done on minor elements in carbonaceous materials, with emphasis on uranium. *Breger* [1958] has reviewed the geochemistry of coal. Data on uranium in carbonaceous materials have been published by *Breger* and *Deul* [1959], *Hail* [1957], *Pierce* and others [1958], and *Vine* and others [1958]. New data on germanium in coal have been given by *Schleicher* [1959]. Determinations of minor elements in petroleum have been made by *Baker* and *Hodgson* [1959] (Mg, Ni); *Beach* and *Shewmaker* [1957] (V); and *Hodgson* and *Baker* [1957, 1959] (Ni, V).

Data on many minor elements in sulfide ores have been published by *Burnham* [1959], who finds marked regional variations, and by *Rose* [1959]. Data on selenium in sulfides have been published by *Coleman* and *Delevaux* [1957] and by *Hawley* and *Nichol* [1959], on copper, lead, and zinc by *Stanton* [1958] and by *Tennant* and *White* [1959]. An occurrence of rhenium, perhaps derived from sulfides, is described by *Petersen* and others [1959] and germanium in the oxidized zone of a sulfide deposit has been studied in detail by *Frondel* and *Ito* [1957].

Many new determinations have been made of minor elements in plants and soils, usually in connection with studies of the biogeochemical method of prospecting for ore deposits. They include: *Bloss* and *Steiner* [1958] (Ba, Fe, Mn, Ni); *Cannon* [1957] (Se, U); *Carlisle* and *Cleveland* [1958] (Mo); *Robinson, Bastron,* and *Murata* [1958] (rare earths); and *Warren* and *Delavault* [1957] (Co). *Pilkey* [1959], *Turekian* [1959], and *Turekian* and *Waage* [1958] have given data on minor elements, especially strontium, in shells.

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Stable-Isotope Geochemistry

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The following bibliography covers the work done in the field of stable-isotope geochemistry in the United States during the period of January 1957 to December 1959. The survey is arranged according to the element investigated and is concerned only with naturally occurring variables in isotopic abundance caused by physico-chemical differences in isotopic molecules.

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SCIENTIFIC HYDROLOGY

LEASON H. ADAMS, *Editor*

Precipitation

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Precipitation frequency studies—The *U. S. Weather Bureau Technical Paper 29 Series*, which consists of five parts and covers the United States east of 90° W, is nearing completion. This series portrays the rainfall intensity—duration—frequency regime for durations of 20 minutes to 24 hours, area from point to 400 sq mi, and frequencies for return periods from 1 to 100 years. A rainfall frequency atlas for contiguous United States is planned for distribution in 1960, and will contain a series of 49 maps for durations of 30 minutes to 24 hours and frequencies for return periods from 1 to 100 years.

Other studies completed within the Weather Bureau and scheduled for publication in the near future include a comparison of extreme rainfall depths from tropical and non-tropical storms [*Hershfield* and *Wilson*, in press] and an empirical appraisal of the Gumbel extreme-value procedure [*Hershfield* and *Kohler*, in press]. Comparisons of several hydrologic characteristics indicated that extreme rainfall associated with tropical storms is not significantly different from extreme rainfall associated with other types of storms. Tests showed that the Gumbel theoretical procedure gives results which compare favorably with observed rainfall frequencies.

At Stanford University, [*Linsley*, 1958] investigated the correlation of rainfall intensity with topography in northern California. This study is part of a long-range program on the hydrology of small watersheds, and its purpose is to show the variation of rainfall intensity over an area in greater detail than possible from observed intensity data alone.

At the Illinois State Water Survey, a detailed study of the frequency distribution of point rainfall for periods of 1 to 10 days in Illinois was completed [*Huff* and *Neill*, 1959]. As part of this study, comparisons were made of several statistical distributions commonly used for rainfall frequency analysis, and several other problems involved in frequency analysis were investigated in considerable detail.

Other papers relating to statistical methods and techniques of frequency analysis have appeared in the literature in the past two years, but space limitations prohibit discussion of them here.

Studies on probable maximum precipitation and floods—A probable maximum precipitation study has been prepared by the U. S. Weather Bureau for the United States west of 105° W and is now in press (*Weather Bureau Technical Paper 38*). This paper provides estimates for durations of 1 to 24 hours for areas from point up to 400 sq mi, and contains a statistical approach to the estimation problem, in addition to the conventional practice of moisture adjustment and storm transposition. *Hydrometeorological Report 35*, entitled, *Meteorology of Hypothetical Flood Sequences in the Mississippi River Basin*, will be published soon by the Weather Bureau. This report discusses several plausible, albeit hypothetical, sequences which would create major flood threats. A report is

under preparation which will be entitled, *Comprehensive Report on Probable Maximum Precipitation, California.* This report will discuss the dynamics of rainfall in various topographic regions and will provide maximum probable precipitation estimates for durations of 1 to 72 hours for any size area in California.

A study is underway at the Illinois State Water Survey to determine area-depth frequency relations in severe rainstorms for Illinois and to investigate the meteorological characteristics of flood-producing storms [*Huff* and *Semonin*, 1958].

Hydrometeorological application of radar—The U. S. Weather Bureau is now installing its new WSR-57 radar which was designed specifically for weather search. The set will be equipped with automatic photo-timing devices for making integrated radar echo photographs [*Staats* and *Tarble*, 1958]. Multiple exposures will be made of the radar scope over 1-hour periods, using Polaroid transparency film. The pictures can be developed, fixed, and projected within a few minutes to allow the radar meteorologist or hydrologist to evaluate the areal distribution of precipitation shortly after it has fallen [*Bigler* and *Tarble*, 1957; *Hiser* and others, 1958; *Tarble*, 1958].

Within the U. S. Weather Bureau a method has been developed for using a radar beacon for telemetering precipitation data [*Soltow* and *Tarble*, 1959]. The beacon is used to collect and display tipping-bucket raingage data on the radar scope, but can be used also for other hydrologic data.

An instrument has been developed at Massachusetts Institute of Technology for averaging radar video signals and range correcting them [*Kodaira*, 1959]. This device should be valuable in making quantitative estimates of rainfall from radar echoes. At the University of Miami, considerable work has been done on the problems of range attenuation correction, signal handling capacity, and photographic integration techniques, all of which are important in radar measurements of precipitation [*Hiser* and *Ray*, 1959; *Hiser, Senn,* and *Conover*, 1958]. *Mueller* [1958] described the development and improvement of an electronic area integrator for precipitation echoes. *Austin* [1958] has presented quite favorable results from comparisons of radar and raingage measurements of rainfall through use of range-corrected radar signals and an isoecho contouring device.

Improved radar equipment operating in the relatively attenuation-free S-band and new readout and display devices should enhance areal precipitation estimations considerably within the next few years.

Cloud seeding research—Very few field research projects in cloud seeding have been conducted during the past two years, but in the field and laboratory much attention has been given to cloud physics. While the scientific literature in the United States during 1958–1959 has contained very few articles directly concerned with cloud seeding, there has been a substantial increase in the quantity and quality of papers on all phases of cloud physics (nucleation, chemistry, precipitation, electrification, dynamics, etc.). Such studies are essential for the proper development and evaluation of cloud seeding. The University of Chicago has been particularly active in cloud physics research. Support provided by the National Science Foundation and other government groups has greatly accelerated advances in this field. The final report of the President's Advisory Committee on Weather Control in December 1957 did much to clarify the status of cloud seeding and stimulate research in cloud physics.

The Santa Barbara project, primarily a statistical study of randomized ground seeding in West Coast winter storms, is now entering its fourth season. Thus far, the statistical evaluation technique has not proven to be sufficiently precise to show whether or not the seeding has produced more rain. Some physical studies are also being performed on storms, to uncover basic cloud-physics concepts and to provide relationships which can sharpen the statistical studies.

The University of Arizona has completed the third season of a program of randomized seeding of summer cumulus clouds. Precipitation, electrification, and cloud growth have been monitored. Analyses suggest that cloud seeding modified the natural cloud processes, but more data are needed to substantiate the indicated results [*Battan* and *Kassander*, 1959]. During the summer of 1958–59, studies of the modification of small cumulus clouds by dry-ice seed-

ing were carried out in Arizona by the Atmospheric Research Group (a California organization).

Several other cloud-seeding projects have been carried on in 1958–59, but will not be discussed here since their primary objectives were other than rainfall production.

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Erosion and Sedimentation

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Dynamics of sediment transport—In a report to the International Association of Hydraulic Research, Carstens noted the small part of the work in the field of sedimentology devoted to the dynamics of sediment transport. Recently, however, a few laboratory studies have described conditions of sediment movement with great care. *Vanoni* and *Brooks* [1957], *Brooks* [1958], and *Simons* and *Richardson* [in press], measuring equilibrium conditions of transport through a range of hydraulic conditions have observed the transition in bed configuration from ripples to dunes to plane bed and antidunes. These studies confirm earlier observations that high boundary-drag coefficients, Darcy-Weisbach f, are associated with the dune phase. E. M. Laursen (Mich. State Univ.) is presently studying pressure distributions on solid and porous fixed dunes. Additional studies by *Vanoni* and *Nomicos* [1957] have shown

further that although the value of f in a stream carrying suspended sediment is less than a comparable one without sediment, due both to damping of turbulence near the bed and decreasing value of Von Karman k with increasing concentration, changes in bed configuration produce much larger reductions than changes in suspended sediment.

Considering the initiation of movement, *Eagleson* and others [1958] described in detail the forces acting on a discrete spherical particle on a sloping beach. *Liu* [1957] ascribed the initiation of dune formation and transport to instabilities developed at the interface between the denser fluid comprising the surface layer of the bed and less dense liquid above. This model has not been explored further either by experiment or analysis.

From analyses of laboratory measurements *Laursen* [1958] has attempted to redefine the relationships between the customary factors used to describe the transport rate of the total load. Computed loads based upon a new equation derived from the laboratory data agreed in part with values measured in three natural channels. These and additional current laboratory studies are reported in an annual publication entitled *Hydraulic Research in the United States* [*U. S. Dept. of Commerce*, 1959].

Mechanism of erosion and definition of erodibility—Neglected since the thirties, interest in the threshold of erosion of cohesive materials has recently revived. Experimental observations by *Dunn* [1959] have shown that the critical 'hydraulic' shear stress required to initiate erosion is directly proportional to a shear strength determined by a vane test apparatus. The experimental results could be expressed by the equation $T_c = 0.02 + (S_v + 180)/1000]$ tan θ where T_c is the tractive resistance and S_v the vane strength. For soils with plasticity index 5 to 16, θ is given by 30 + 1.73 PI (plasticity index). For the soils investigated in the laboratory and field the critical tractive stress increased with a decrease in mean particle size, $\theta^\circ = 15.5$ (Phi Mean $- 2.3)^{0.666}$, and for those containing a sand component, critical stress could be predicted from the percent silt and clay, $\theta^\circ = 0.6$ (% of sample <0.06 mm). The results were compared with the critical tractive forces suggested by Lane for design of stable channels. Smerdon and Beasley found that the critical tractive force correlated best with the plasticity index (PI) or the dispersion ratio. Their results varied somewhat with the mode of computation of the tractive force. In general $T_c = K$ (PI)^n where K is either 0.0022 or 0.0034, and $n = 0.82$ or 0.84.

Geologic and geomorphic aspects of erosion and sedimentation—In a study of streams in Virginia and Maryland, *Hack* [1957] has shown that the shape of the longitudinal profile is determined by the type of bedrock and the discharge of the drainage basin. Simple formulas show that slope s is directly proportional to median particle size M and inversely proportional to drainage area A, $S = 18\ (M/A)^{0.6}$. Channel length is also proportional to drainage area and the mode of supply and breakdown of particles determines the differential concavities of profiles in different lithologies.

Field and laboratory studies of river channel shape and form [*Leopold* and *Wolman*, 1957] illustrate the continuous character of the adjustments of slope, discharge, load, and bed and bank material which alternatively lead to the development of braided, meandering, and straight channels. The ratio of meander length to channel width (7 — 12 to 1) is also frequently observed in the spacing of pools and riffles in straight channels. At a given discharge, meanders customarily occur on lower slopes than braided channels. All patterns may represent conditions of equilibrium and thus braiding is not necessarily evidence of excess total load. Studies of floodplain stratigraphy and frequency of flooding on a number of streams indicate that the floodplain is constructed primarily through lateral migration and deposition of point bars. The active flood plain thus formed appears to be flooded on the average once each year or every other year [*Wolman* and *Leopold*, 1957]. The effect of major floods on flood-plain formation and destruction is highly variable and depends in part on rainfall intensity, availability of sediment, and valley form [*Wolman* and *Eiler*, 1958]. Of unusual interest are relatively well-established rates of valley alluviation in New Mexico determined by *Miller* and *Wendorf* [1958] from C-14 dates and detailed pottery chronologies.

Through the application of dimensional analysis *Strahler* [1958] has developed a number of dimensionless parameters describing the sig-

nificant geometric and dynamic properties of drainage basins. Geometric ratios including length, relief, drainage density, and ruggedness when combined with dimensionless ratios analogous to Reynolds and Froude numbers permit rational comparisons of different drainage basins of diverse sizes as well as consistent descriptions of drainage changes resulting from accelerated erosion. *Melton* [1958] using more elaborate mathematics, has found that valley side slope is directly related to the square root of relief and fourth root of channel length, and inversely proportional to the 0.75 power of the drainage area. He has drawn attention, however, to the important distinction between growth models of landform development and comparison of different forms in space. In the absence of direct evidence for the time sequence, Melton constructed a hypothetical succession based on data from three fifth-order basins which shows (1) a close relation between stream number and length, and (2) that deviations in bifurcation ratios (Horton) are compensated by changes in length ratios.

Erosion, transportation, and deposition of sediment in watersheds—Perhaps because of its immediate applicability, research in watershed sedimentology has received somewhat more attention than the previously mentioned fields. In a major paper analyzing the regional interrelations of vegetation, precipitation, and sediment yield, *Langbein* and *Schumm* [1958] observed that peak sediment yields were derived from regions experiencing approximately 15 inches of effective precipitation. Below that amount sediment yield increases with precipitation; above it, vegetation inhibits sediment yield and yield thus decreases with increasing precipitation. Recently, emphasis has been placed on determining the relationship between sediment yield and gross erosion. This information is necessary in the proper planning and design of projects for development of land and water resources. Detachment of soil by rainfall impact (rainfall-erosion index) has been studied in considerable detail and has been incorporated in a 'soil-loss equation.' The rainfall erosion index is the product of the kinetic energy and the 30-minute intensity of the rain storm. The interrelationship between this index and the other watershed factors in the equation are discussed in papers by *Wischmeier* [1959, in press]. Movement of detached material to downstream points is determined by comparing the tonnage of material detached and the tonnage passing a particular point. The ratio of the two is generally referred to as the sediment-delivery ratio. Evaluation of the effect of present and future watershed use and conservation programs may be included in such analyses, as reported by *Spraberry, Woodburn,* and *McHenry* [1959]. *Renfro* and *Moore* [1958] using computed values for sheet and channel erosion and records of reservoir sedimentation in the Western Gulf States have shown that sediment delivery rate (percent of gross sheet erosion) decreases exponentially with increasing drainage area and increases exponentially with the ratio of basin relief to channel length. *Stall* and *Bartelli* [1959] in a detailed study found that sediment deposition in 20 lakes in Illinois was related to capacity-inflow ratio, sheet erosion, slope, channel density, and direct tributary inflow. Although all such studies apply to specific regions, from them a physiographic pattern may be slowly emerging.

Considering sediment transport in natural channels, *Hubbell* and *Matejka* [1959] compared rates of sediment transport based on numerous equations in the natural channel of the Middle Loup River with values of the total load derived from samples taken at a turbulence flume constructed across the channel. For this reach a channel with sand bottom experiencing relatively small fluctuations in discharge, and a moderate range in sediment concentration, total loads computed by the modified Einstein procedure averaged 81% and ranged from 26 to 150% of the measured total loads. Computations based on the Meyer-Peter and Muller equation for a single cross section appeared to be accurate measures of the actual bed-load discharge. Selection of representative cross sections for computations was particularly important in all comparisons. For the Nebraska sand-hill streams, the measured exponent z_1 (describing the vertical distribution of suspended sediment) differed from z based on the fall velocity and varied inversely with the Von Karman coefficient k, the latter ranging in value from 0.4 to 4.0 *Stall* and others [1958] found that of several bedload equations tested, results of computations based on the Schoklitsch equation

agreed most closely (error 31%) with the amount of sediment estimated to have been contributed to a reservoir by Money Creek in Illinois. Several recent papers have emphasized the importance of sediment control in maintaining channel stability below structures [*Borland* and *Miller*, 1958, 1959; *Friedkin*, 1959] and several continuous field observations [*Parsons*, 1959; *Wolman*, 1957] have attempted to define the conditions controlling erosion of channel boundaries. Recent laboratory studies of boundary shear stress [*Nece* and others, 1959] and of the effect of channel curvature on resistance to flow [*Leopold* and others, in press] should lead to increased understanding of the mechanism of channel erosion.

Supporting laboratory and earlier field observations, studies by *Colby* [in press], and *Carey* and *Keller* [1957] emphasize the importance of the configuration of the beds of aluvial channels in modifying the form of the rating curve in natural rivers.

Because of its importance in reservoir capacity and design, the problem of amount, disposition, and characteristics of sediment deposited in reservoirs continues to receive attention. A key to basic data is provided in the *Summary of Sedimentation Surveys* [*Interagency Comm.*, 1957]. In addition, some empirical procedures have recently been developed for use as guides in predicting distribution. The procedures give a method of predicting the sediment accumulation at the dam, and the amount of deposition probable in the various storage allocations for a given amount of sediment inflow [*Borland* and *Miller*, 1958, 1959; and Heinemann, in press]. A noteworthy analysis of the mechanics of reservoir delta development based on changes in transport in the backwater reach is given by *Fowler* [1957]. Reservoir trap efficiency is the subject of a current joint study of the U. S. Geological Survey and the U. S. Soil Conservation Service.

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Evaporation and Transpiration

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Developments in mass-transfer theory and applications to measurement of evaporation and evapotranspiration—The Laboratory of Climatology in Centerton, New Jersey, where pioneer work on mass-transfer theory has been done under the direction of C. W. Thornthwaite, reports experiments on a method of measuring the flux of water vapor from any natural surface, by precise measurement of the water vapor density (absolute humidity) at a single convenient level above the evaporating surface and the simultaneous determination of the vertical motion of the air at that level. These measurements are made possible through the use of newly developed instruments; a refined automatic dewpoint hygrometer and an anemometer for the vertical wind.

The new dewpoint hygrometer utilizes the

Peltier effect for thermoelectric temperature control of the dewpoint mirror. A thermistor gives the temperature of the dewpoint mirror as absolute humidity. The vertical component of the wind is obtained by a specially developed vane which is substituted for the cup assembly on the sensitive anemometer of the Thornthwaite wind-profile register system. The vane has a linear response to the vertical wind and rotates in opposite directions for updrafts and downdrafts. The two instruments are linked together in such a way that the moisture of every rising and descending layer of air is registered. The ascending units of moisture are added and the descending units subtracted; the total is the evaporation.

This method avoids the problems of the old mass-transfer method altogether. No turbulence theory is involved. It is not necessary to define the evaporating surface or to determine roughness parameters. The method has not been tested extensively as yet, and it is not yet assured that all of the difficulties have been eliminated.

Studies in the use of the energy balance for the determination of evaporation and evapotranspiration—An investigation of the use of a miniature evaporation pan as a radiation integrator was initiated by J. B. Franzini of Stanford University with funds from the U. S. Weather Bureau. Tests have been run on several small evaporation pans (4- to 8-inch diameter). A continuous record of pertinent temperatures was recorded.

An energy-budget analysis of the data is being made. The standard of comparison is the record from a Beckman-Whitley flat-plate net radiometer suspended over a class A evaporation pan. The objective of the research is to determine the feasibility of a small portable Cummings radiometer.

A field test of the energy-balance method of measuring evapotranspiration was conducted in Nebraska under the technical supervision of O. E. Leppanen of the U. S. Geological Survey, according to a report from G. E. Harbeck, Jr. Evapotranspiration was determined using a water-budget control, and field data were obtained to permit computation by both energy-budget and mass-transfer methods. A report is being prepared.

The use of climatological data for consumptive use studies—The New Jersey Pine Barrens Hydrologic Research Project under the direction of E. C. Rhodehamel of the U. S. Geological Survey is studying the amounts and seasonal distribution of consumptive-use losses from two small forested watersheds in south-central New Jersey. A water-budget method of study is being used. Hydrologic and meteorological parameters used are: (1) Weekly and monthly precipitation amounts from a one-gage-per-square-mile network. (2) Continuous stream-discharge measurements. (3) Daily average ground-water fluctuations and ground-water elevations for the watersheds determined from a network of about 60 wells, including continuous recording wells, in each watershed. (4) Mean daily, weekly, and monthly temperatures from a nearby U. S. Weather Bureau station.

Five years of continuous records of these data are currently being evaluated. The studies are to be continued. The consumptive-use studies are a part of the study to determine the effects caused by forest-management practices on interception, infiltration capacity, evaporation, and water yield from the water-table aquifers in the New Jersey Pine Barrens region.

As a part of an analysis for single-watershed control at the Dilldown Watershed in Pennsylvania, it was found that water loss could be predicted with considerable accuracy on a monthly basis, according to I. C. Reigner of the U. S. Forest Service. The term 'water loss' as used here may be defined by these basic equations:

$$\text{Water Loss} = \text{Precipitation} - \text{Streamflow}$$

and

$$\text{Water Loss} = \text{Evapotranspiration} \pm \text{Storage Changes}$$

To estimate water loss, the following parameters were used as independent variables in a multiple regression equation: (1) ground-water storage at the beginning of the month; (2) precipitation for the month; and (3) average length of day for the month.

The first parameter, ground-water storage, may be derived from hydrograph analysis or may in turn be estimated from climatological data. The parameters used in this estimation are: (1) monthly sums of temperatures over 30°F, and (2) weighted sums of daily precipitation for an antecedent period. The length of the antecedent period depends on the month involved.

Although consumptive use as an individual

element is not estimated in this procedure, it is part of the total with which this study is concerned. If the storage factors, ground water, and soil moisture, could be measured accurately on a watershed basis, consumptive use would then be just as accurately measured and related to climatological data.

The U. S. Forest Service reports that evapotranspiration determinations on areas covered by aspen, spruce, and grass at 9800-foot elevation in southwestern Colorado showed losses to be greatest under aspen. Average loss for 2 years during the growing season was: aspen 19.04 inches, spruce 14.50 inches, and grass 9.78 inches.

Progress in the use of monomolecular films for the suppression of evaporation—W. J. Roberts of the Illinois State Water Survey Division reports that, with respect to the use of monomolecular films for the suppression of evaporation, they achieved during 1957 and 1958 savings of from 22 to 43% of the water normally lost to evaporation from two small Illinois lakes. In the summer of 1959 the technique was applied to a municipal water-supply reservoir with results that prompt the municipality to plan similar treatment in 1960.

Progress has been made on emulsifying chemicals used to produce monomolecular films.

The following papers have been published:

Roberts, W. J., Evaporation suppression from water surfaces, *Trans. Am. Geophys. Un.*, **38**, 740–744, 1957.

Roberts, W. J., Reducing lake evaporation in the Midwest, *J. Geophys. Research*, **64**, 1605–1610, 1959.

A study of evaporation suppression and effects on biota is being conducted by J. B. Franzini at Stanford University and is being financed by a U. S. Public Health Service research grant. As yet, no conclusive results have been obtained. Some preliminary work in search of a film with optimum healing properties has been conducted using a Langmuir tray. Tests on six class A evaporation pans have been made using different chemicals at various dosages.

A wind-actuated dispenser which will eject a fine spray of molten hexadecanol (140°F) is being developed. In the summer of 1960, a film will be applied to Felt Lake (40 acres); the evaporation reduction will be evaluated by water budget and energy budget. In future years an evaluation will be made of the effects of a film on biota in the lake.

Use of hexadecanol on a standard Weather Bureau evaporation pan reduced evaporation 42 percent during the period May through September near Portland, Oregon, H. C. Storey of the U. S. Forest Service reports.

G. E. Koberg of the U. S. Geological Survey reports that preliminary results from tests on small reservoirs in Texas indicate that evaporation was reduced as much as 20% during 1959. Wind-controlled dispensers were developed to apply the film-forming material from only the containers on the upwind side of the lake.

During the summer of 1958 a study was made at Lake Hefner, a water-supply reservoir at Oklahoma City for the purposes of testing methods of applying and maintaining a hexadecanol film, evaluating the reduction in evaporation, and investigating the hydrologic, water quality, public health, and economic aspects of such a treatment. Those collaborating in the study included federal, state and municipal agencies.

It was found that techniques are available to cover the 2500-acre Lake Hefner with a fully compressed monolayer of hexadecanol, given favorable conditions. During the treatment period. July 7 to October 1, 1958, the reduction in evaporation was 9%. No hexadecanol could be detected in water reaching the city intake. It was found that concentrations of micro-organisms normally present in lake waters increased markedly as a result of feeding on the hexadecanol, but the purified water met accepted public health standards.

Studies of the areal variation in evaporation in the United States—The techniques described in the *Lake Hefner* and *Lake Mead Water Loss Investigation Reports* and *Weather Bureau Research Paper No. 38, Evaporation from Pans and Lakes*, have been used to develop evaporation maps for the United States, according to T. J. Nordenson of the U. S. Weather Bureau. These maps have been published in *Weather Bureau Technical Paper No. 37, Evaporation Maps for the United States*. The report contains a brief text describing the methods used and the following series of maps: Plate 1, Average annual class A pan evaporation; Plate 2, Average annual lake evaporation; Plate 3, Average annual class A pan coefficient; Plate 4, Average May–October evaporation in percent

of annual; and Plate 5, Standard deviation of annual class A pan evaporation.

A report is being prepared by J. S. Meyers of the U. S. Geological Survey listing gross evaporation losses from reservoirs, lakes, ponds, and streams in the 17 western States. Water-surface areas were determined for each State and river basin, and the U. S. Weather Bureau evaporation map mentioned by Nordenson was used to compute the total volumes of evaporation.

Potential evapotranspiration—A recent study in Puerto Rico showed soil-moisture depletion rates to be about one-half those in the U. S. on similar sites. This apparently bears out Wilm's observation that in humid areas with excessive precipitation, evapotranspiration opportunity may actually decrease with increases in precipitation above evapotranspiration potential, according to H. C. Storey of the U. S. Forest Service.

Lysimeters—Developments and experiments, with a continuously recording weighing lysimeter for determining the amount of interception by forest litter, are being carried on by the U. S. Geological Survey in cooperation with Rutgers University.

T. E. A. van Hylckama is responsible for the technical direction of an evapotranspiration study begun by the U. S. Geological Survey in cooperation with the U. S. Bureau of Reclamation. Six lysimeters, each having a surface area of about 1000 square feet, were constructed in the Gila River valley near Phoenix, Ariz. The object of the study is to determine consumptive use by salt cedar (tamarix gallica) under different depths to the water table.

Glaciers

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Glaciers in the United States: census and mapping—Knowledge of the extent and distribution of glaciers is necessary for an appraisal of either the scientific or practical problems connected with them. About 51,000 km² of glacier ice exists today in Alaska; the next most highly glacierized State is Washington (about 350 km²); third is Wyoming (about 44 km²). For the first time, the glaciers in the virtually unknown northern Cascades of Washington and the eastern Brooks Range of Alaska were cataloged.

Precise topographic maps were compiled for 20 glaciers using terrestrial and aerial photogrammetry; these will be remapped in later years to determine volume changes. Seismic and gravity surveys revealed the ice thickness and the configuration of the subglacier floor of Lemon Creek Glacier (Alaska) and Blue Glacier (Washington).

Extent and thickness of ice in Antarctica—Some 12,000 km have been covered by traverse parties to date, mostly in West Antarctica. Seismic and gravity measurements have provided fairly detailed ice-thickness determinations along the traverse routes. The ice thickness throughout West Antarctica was found to be much greater than expected, and a large part of the subglacier rock surface is known to below sea level. The Filchner Ice Shelf extends more than 600 km inland and is comparable in size to the Ross Ice Shelf. A vast ice-filled channel several hundred kilometers across with a maximum depth greater than 2500 meters below sea level exists between the Sentinel Mountains and the Executive Committee Range, and probably ex-

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tends from the Ross Sea to the Bellingshausen Sea. Troughs with water depths of 1000 meters or more have been found beneath the western edge of the Ross Shelf and the eastern edge of the Filchner Shelf. The coastal ranges between the Ross and Bellingshausen Seas probably comprise a series of mountainous islands.

A layer of ice about 300 meters thick in which the seismic wave velocity is decidedly low was found at the bottom of the ice cap in Marie Byrd Land. This may consist of ice at or very near the pressure melting point.

Regimen, fluctuations, and hydrology of mountain glaciers—Detailed regimen studies were made on Blue and South Casade Glaciers in Washington and Lemon Creek and McCall Glaciers in Alaska, which include climatic environments ranging from highly maritime temperate to sub-polar continental. The mass budget of all these glaciers during the 1957–1958 budget year was strongly negative. This appeared to be an unusual year, at least for the two glaciers in Washington, for generally positive regimens had been observed during the previous decade. The relation of surface accumulation and ablation to glacier flow was investigated on Lemon Creek and South Cascade Glaciers. For the first time in the United States, intensive studies of glacier hydrology were begun, with instrumentation installed at South Cascade and Grinnell Glaciers. Present fluctuations of glaciers, as indicated primarily by changes in their terminal areas, were studied most extensively in southern Alaska and western Washington. Recent climatic trends are being evaluated in relation to the glacier regimen data.

Regimen and fluctuations of the Greenland and Antarctic ice caps—Glaciological and snow studies were conducted in both northern and southern Greenland during the summers of 1958 and 1959 by Snow, Ice, and Permafrost Research Establishment (SIPRE) personnel. Research on the traverses included determination of the past several years annual accumulation, mean annual temperature, and areas of melt. Density, grain size, stratigraphy, and rammsonde measurements were made, in addition to general altimetry and meteorologic observations.

Snow accumulation was measured in pits and boreholes and by means of snow stakes at most United States bases and traverse stations in Antarctica. Detailed analyses of variations in snow stratification and accumulation in Antartica are now under way. It has been found that data obtained from pits are not entirely unambiguous because of the local variations in erosion and deposition. The genesis and movement of sastrugi are being studied in order to gain information on wind direction and intensity and variability of point values of accumulation. Examination of the glacial deposits in the McMurdo Sound region revealed that both alpine and outlet glaciers have fluctuated widely in the geologic past, and at least three major Quatenary glaciations are recorded.

Micrometeorology of glaciers and ice caps—Detailed, year-around studies of surface energy exchange were made during IGY on the Blue Glacier in Washington, and on the McCall Glacier in northeastern Alaska. The Blue Glacier work continues as a summer field program.

In order to collect material for a heat-balance of Antarctica, measurements and records of direct solar radiation, global radiation, albedo, long-wave radiation, and net radiation were performed at Little America V between February 1, 1957, and February 3, 1958. On the inland ice, 100 series of albedo measurements were taken at the South Pole Station during December 1957, and 15 series at Marie Byrd Station in January 1958.

Glacier flow: velocity, deformation, and structures—Detailed measurements of surface and englacial velocity made on Blue Glacier, Washington, yielded basic data for the analysis of the flow law of ice, the geometry of flow, and the relation of deformation to the formation of structures and the orientation of ice crystals. Other velocity measurements were made on 11 glaciers from Alaska to Antarctica, utilizing techniques ranging from conventional triangulation to time-lapse photography. Precise position locations made at the South Pole and at several other stations in Antarctica and Greenland will be repeated in later years to reveal movement of the ice. An investigation of the deformation of a portion of the Ross Shelf Ice in Antarctica led to conclusions about the strain pattern in this active area and the mode of origin of crevasses and anticlinal folds.

Structural investigations of the Blue Glacier, Washington, suggest that a double nested spoon-shaped foliation pattern seen in this

glacier originates within a zone of intense compressive flow at the base of an ice fall. An unusual longitudinal septum is attributed to the splitting of ice currents in the ice fall by a rock bastion. Internal ogives in this glacier are believed to represent greatly compressed, recrystallized and modified insets of ice breccia filling crevasses in the ice fall.

Fabric studies on the Blue Glacier show that fine ice almost universally displays a broad single maximum centered about the pole to the foliation plane. Coarse-grained ice exhibits multiple maxima which possibly have evolved from the single maximum of fine ice by recrystallization.

Deep-drilling projects in Greenland and Antarctica— Previous glaciological work has shown the need for a deep-drilling program which would provide cores for analysis and precise measurements of temperature and deformation. A rotary drilling rig using compressed air as a drilling fluid was developed by SIPRE. Holes were drilled to 1000 and 1348 feet in Greenland. A 1000-foot hole was drilled at the Marie Byrd Station in the Antarctic during January and February of 1958, and a hole drilled all the way through the 840-foot floating ice shelf at Little America Station a year later. Cores from both Greenland and the Antarctic have been returned to the SIPRE laboratory for examination. Measurements of temperature, diameter, and inclination are continuing to be made on the drill holes.

The oxygen-isotope program—Recent analyses of oxygen-isotope ratios (O^{18}/O^{16}) in ice, firn, and snow from glaciers in Alaska, Canada, United States, Greenland, and Antarctica suggest that such data may contribute significantly to an understanding of various glaciological relations. For example, annual layers are still identifiable by this means in cores from as deep as 1300 feet in the Greenland ice sheet. Snow from the South Pole proved to be the lightest natural precipitation (relatively deficient in O^{18}) yet analyzed. Analyses of material from other glaciers have been used to check deductions concerning flow lines, source of material, origin of types of ice, and the genesis of structures.

Arctic sea ice studies—A comprehensive sea-ice program encompassing meteorology, micrometeorology, oceanography, crystallography, and ice mechanics has been conducted in the Arctic Basin since 1957. Research work on floes was concentrated at Drifting Station Alpha during IGY, and, after this station was abandoned late in 1958, was continued on Drifting Station Charlie in 1959. A smaller continuous program has been maintained on Station Bravo, situated on ice island T-3. A micrometeorological study pertaining to sea ice also exists at Point Barrow.

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Ground Water

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Introduction—Some significant changes in emphasis have been made and new subjects of study in ground-water hydrology have been undertaken in the United States during the past few years. They were brought about by an increased and diversified development of systems to meet the needs of the great urban and suburban expansion and its associated water requirements and the unique hydrologic problems involved in new industry, such as the development of nuclear energy.

As the amount of water developed and areas of development have expanded, it has been necessary to place more emphasis on tying together the scattered and somewhat disconnected studies of municipal county, or small basin areas carried on in the past, into regional studies that will provide a foundation of knowledge for supporting the development and management of entire hydrologic systems or of large areas or regions in which there is some similarity in the types of aquifers and in the use of water. Some of these regional studies encompass many States and require the coordinated work of many local, State, and Federal agencies.

As the demand for water increased, more refined quantitative answers were needed but it has been more fully realized that the existing mathematical formulas are limited in their application primarily because of the complexity of geologic conditions. Therefore, emphasis has been directed toward developing more versatile analytical methods that will take into account the variable geologic conditions common to most ground-water systems. This in turn has made it necessary to relate the geology to the hydrologic parameters that are significant in determining the characteristics of hydrologic systems.

In addition to these major areas of interest, much work is being accomplished on some of the special problems in the field, such as waste disposal, salt-water encroachment, artificial recharge, evapotranspiration and arid-zone hydrology and mining hydrology.

Regional and hydrologic-system studies—Initially, the water needs of the United States were concerned largely with exploration and development; but, as development expanded, competition for available sources intensified and the principal problem has become one of water-resources management.

The pressures related to the growth of a more diversified economy, from a base of irrigation agriculture, brought the States in the semiarid and arid parts of southwestern United States to an early realization of the importance of water-resources management. Some of the first studies of regional scope started in the arid part of the country, and subsequently have progressed eastward.

The distribution of areas for which there is substantial ground-water information in the United States that has been collected as joint cooperative programs between State and local agencies and the Federal Geological Survey is shown by Figure 1. Although this map does not include some investigations being carried on independently by such States as Illinois, Missouri, California, or universities, it illustrates the pattern of knowledge on ground-water resources, and the need to tie some of these areas together into broader regional investigations.

The largest regional investigation presently underway is the study of the water resources of the upper part of the Mississippi Embayment. The project covers 90,000 sq mi of the Gulf Coastal Plain of the United States and includes parts or all of 9 States. The study has resolved many differences in stratigraphic in-

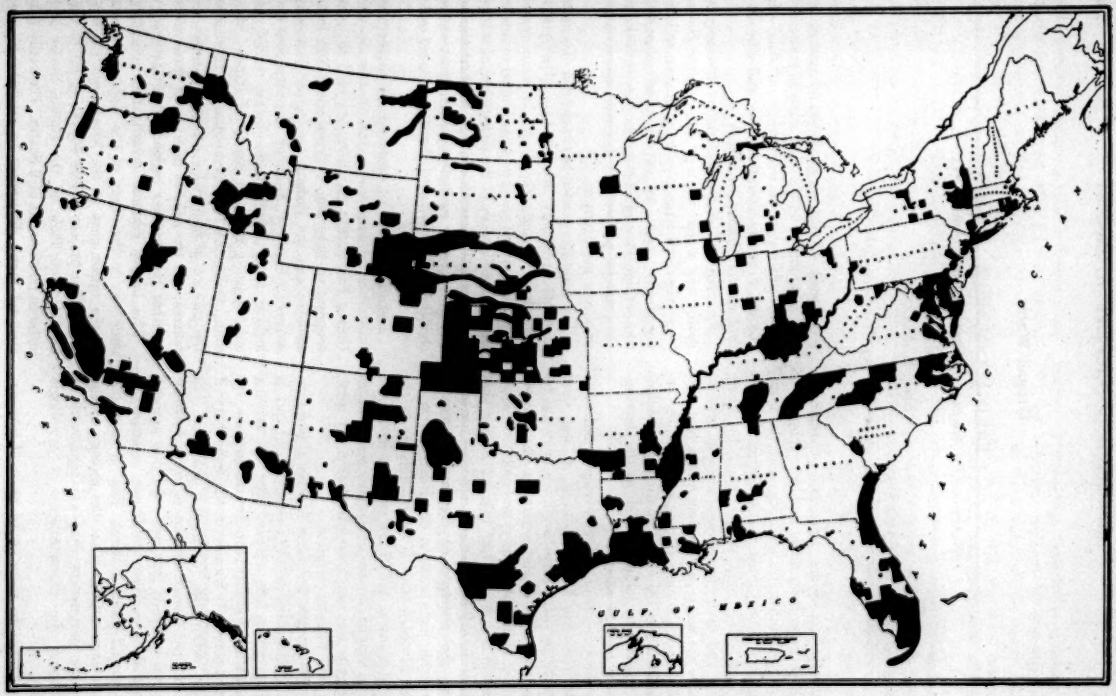

FIG. 1—Areas of substantial ground-water information

terpretation and has provided data for regional analysis of hydrologic systems. Other such studies include the Edwards limestone area in Texas, the basalt aquifer of the Snake River plain in Idaho, and limestone terranes of the Midcontinent area.

Development of principles and methodology—The emphasis on studying large areas or hydrologic systems stimulated the development and application of analog models, particularly electrical models. Models, which simulate the conditions that exist in nature, are much more realistic and versatile than the mathematical formulas which assume relatively uniform conditions and aquifers or hydrologic systems having relatively simple geometry. Thus, with the development of analog-model methods, the determination of the internal and external boundaries of hydrologic systems has become a primary goal in many ground-water studies. Obviously, it is not practical to measure directly the transmissibility or permeability over large areas; hence, lithofacies maps, stratigraphic studies, flow-net analyses, subsurface geophysical data, etc., are being used increasingly to relate geology to hydrologic parameters for analysis by the analog methods.

Analysis by mathematical formulas, however, is still being refined and used, but primarily for problems involving relatively small parts of aquifers or aquifers of relatively small areal extent. The basic equations have been modified to cover aquifers having various shapes and boundary conditions.

The regional studies have also caused a greater emphasis on investigations to determine the factors and processes governing the spatial distribution of chemical elements in ground water.

Inasmuch as large withdrawals of water cause a compaction of some types of water-bearing and associated sediments, special studies have been undertaken to determine the cause of the compaction and its significance in ground-water development. This is especially important in the compression and possible expansion of artesian aquifers.

Studies relating to the disposal of liquid wastes have involved both theoretical and experimental investigations of the degree of dispersion of liquid contaminants and the effects of heterogeneity on the rate and direction of movement in aquifers. Radioactive and chemical tracers have been used in such experiments. Tritium has been used as a means of determining the age of relatively young ground water, in addition to use as a tracer.

Other studies concerning the development of methodology and principles have included the design and construction of instruments for measuring the vertical distribution of velocity and the yield of different aquifers in discharging wells, and the fluctuations of water levels in small-diameter wells, and laboratory experiments relating quantity of flow to pressure change with respect to time under nonsteady conditions.

Selected problems—The areal and regional field studies have brought to light many problems requiring special study to develop a clearer understanding of particular relationships and processes involved.

Studies are in progress in several areas to identify the hydrologic characteristics of groundwater flow systems that are subject to encroachment by mineralized waters. In coastal areas the problem is concerned with sea-water encroachment in aquifers as a consequence of hydrodynamic imbalance which accompanies withdrawal of fresh ground water.

The effective and safe disposal of industrial wastes, such as some of those resulting from the development of atomic energy, as well as the increased application of artificial recharge, have brought about a greater emphasis on field studies on the rate and direction of movement of fluids in both the unsaturated and saturated zones.

Numerous field studies are in progress to evaluate the different methods for artificial recharge by surface spreading and by injection through wells. Investigators are exploring the effects of different methods of recharging, the influence of land use and surface preparation, the problems of water treatment, the maintenance of infiltration structures, and the physics of infiltration processes.

Studies of the hydrology of selected mining areas are being made to evaluate the factors influencing the flow of water into mines which would be flooded if the ground water were not kept under control. The mining areas generally are characterized by rocks of low permeability, in which the mines simulate huge wells toward which steep hydraulic gradients develop.

There has been increasing emphasis on studies of arid-zone hydrology, particularly with respect to evapotranspiration and its role in the hydrologic cycle. Much work has been done in investigations of consumption of water by phreatophytes of the arid and semiarid parts of the country, and field studies in some areas have determined the magnitude of the water loss by plants. Other factors important to arid-zone hydrology which are under study include (1) conversion of water of marginal chemical quality to fresh water, (2) salvage of natural discharge, particularly that water lost by evapotranspiration, (3) artificially induced precipitation, and (4) feasibility of reclaiming water from sewage for certain uses.

In summary, significant changes in ground water studies place more emphasis on the areal investigations of occurrence, movement, quantity, and geochemistry of water in aquifers along with the geology of these aquifers and associated formations.

Snow and Ice

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Snow and ice properties—The most notable work in progress is the basic research in progress at the Snow, Ice, and Permafrost Research Establishment (SIPRE) of the Corps of Engineers where ultimate-strength studies of snow, ice and sea ice have been related to measurable parameters of density, temperature, and composition. Techniques have been developed to determine the structure of low density fragile snow. Viscoelastic properties of snow and ice have been determined and field equipment developed for studies of this. Large single crystals of ice have been grown in the laboratory and experiments completed on the linear thermal expansion of ice crystals. Snow has been modeled in a wind tunnel for snow drifting problems. Studies have continued on the growth and melting of lake and sea ice as a function of snow cover and meteorological conditions.

The Corps of Engineers has likewise continued development of a radio-reporting isotope snow gage for automatically transmitting water content of snow. Studies have continued at the University of Idaho of measurement of precipitation in the form of snow and the University of Idaho and Utah State University have initiated a basic study of methods of measuring water content of snow *in situ*. The Weather Bureau reports attempts at identifying precipitation in the form of snow by radar. Chemical constituents in snow at specific locations have been studied by the U. S. Geological Survey at two locations in western United States.

Snow melt and thermodynamics—The Pacific Southwest Forest and Range Experiment Station working at the Central Sierra Snow laboratory has reactivated basic studies on snow melt. F. A. Camp, Los Angeles City, has reported on observation in that same area of California. Related Forest Service studies have also been in progress at Frazer Experimental Forest in Colorado. A comprehensive report of this work was published in March 1958 entitled *Factors Affecting Snow Melt and Stream Flow*. Additional processing has been reported of data collected at the cooperative snow laboratories. Wilson and Weis reported on *Snow-Melt Degree-Day Ratios Determined from Snow-Lab Data*. Hanson of the Weather Bureau also reported on radiation measurements on a south polar snowfield.

Snow and ice movement (not glaciers)—Studies have continued at SIPRE on creep of snow and ice under combined stresses. Blowing snow

problems in connection with Arctic construction are being studied at New York University for SIPRE.

Operational forecasting from snow surveys—This activity has continued to expand and extensive operational research is being done by the Soil Conservation Service, the California Department of Water Resources, western Districts of Corps of Engineers, private power companies, and the Bureau of Reclamation. These studies are principally reported in the *Proceedings of the Western Snow Conference*. Important advances have been made in graphical and statistical correlation techniques and in introducing new parameters that influence runoff. The use of computers and procedures for utilizing mechanization of processing of snow data has come in for considerable attention.

Environmental influences on snow and snowmelt runoff— Principal work in this field has been the investigations carried on by the Forest Service in connection with water management research. Influences of cover, wind, exposure, and logging operations have been under investigation. Studies are centered at Soda Springs, California, and Frazer, Colorado. Criteria for selecting snow-measuring stations has come in for studies by the Forest Service and the Soil Conservation Service.

Moisture loss from snow and ice surfaces—Evaporation studies from snow in storage have been under investigation in Colorado, at Frazer Forest, at high alpine locations in Colorado, and also in Wyoming. Snow-ablation studies are also in progress on the Blue Glacier in Washington.

Of interest to the people in snow and ice is the passing of two of the most illustrious scientists of the United States. Charles Franklin Brooks of Harvard's Blue Hill Meteorological Observatory died January 8, 1958 and James Edward Church, the recognized father of snow surveying died August 5, 1959, at age 90.

References to specific articles are not included because it is felt that the *Bibliography on Snow, Ice, and Permafrost* with abstracts as published by SIPRE is a much easier place to seek out this detail. Perhaps mention should be made of this important contribution that is being continued.

Surface Runoff

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Use of radioactive tracers in hydrologic measurements—The use of radioactive tracers to study phenomena in hydrology that have not previously been easily amenable to investigation is proceeding at a rapid pace.

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Hydrologic forecasting (*M. A. Kohler, U. S. Weather Bureau, Washington, D. C.*)—The use of radar to evaluate basin rainfall has received widespread attention in recent years [*Hiatt*, 1956; *Ligda* and others 1956; *Bigler* and *Tarble*, 1957; *Mueller*, 1958; *Hiser, Ray*, and *Conover*, 1958; *WMO*, 1959]. The Weather Bureau has operated many WSR-3 (converted, airborne) radars and, although this equipment is not particularly suited for hydrologic purposes, the results have been promising. Hydrologic requirements are fully considered in the design of the new WSR-57 radar [*Rockney*, 1958] which is to be installed at 31 sites over continental United States of America.

Although our experience with the new type radar is still extremely limited, its capabilities in determining the areal distribution of precipitation intensity appear to be highly satisfactory. To assist in evaluating radar images, beacons have been developed [*Soltow* and *Tarble*, 1959] which display measured rainfall at selected points over the area directly on the radar scope.

Our studies indicate that basin accounting techniques [*Kohler*, 1957] constitute the best approach to the problem of estimating runoff from rainfall and other related factors. We are in the process of evolving a standard accounting system which will provide reliable results over the wide range of climatic and hydrologic conditions encountered.

Flood forecasts often hinge upon an extrapolation of a stage-discharge rating curve beyond the segment defined by current meter measurements. To avoid reliance upon an eye-extrapolation of the defined rating curve, we are investigating extrapolation techniques which utilize data on channel configuration [*Stevens*, 1907; *Linsley* and others, 1949].

Water-supply forecasts for the Columbia Basin are now prepared on an IBM 650 computer, and it is planned that all such long-range forecasts will eventually be prepared on computers. Basin soil-moisture accounting computations have been programmed for the IBM 650 [*Engelbrecht*, 1959] and the Bendix G15D [see also *Rockwood*, 1958; *Paynter*, 1955; *Swain and Riesbol*, 1959].

The feasibility of extended low-flow forecasts for pollution control, navigation, etc., is now under investigation. Forecasts of ice conditions are also important to navigation and studies are now underway to develop reliable methods of preparing these forecasts.

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Stream gaging network design (J. E. McCall, U. S. Geological Survey, Trenton, N. J.)—Recognizing the impossibility of operating stream gaging stations at all points where data will be needed in future years, hydrologists in the United States have developed concepts and criteria for areal rather than point stream gaging.

About one-third of the existing stations have been selected for permanent or long-term operation to sample variations in flow with *respect to time*. These stations, called areal primary stations, were chosen because they represent natural runoff, are distributed fairly uniformly over the whole country, and each is considered a reasonably good index of runoff in other nearby streams.

Another one-sixth of the existing stations have been designated areal secondary stations and will be operated only long enough to develop a firm correlation with one long-term primary station. These secondary stations sample variations in daily flow with *respect to place* in successive locations around a primary station.

Additional sampling with *respect to place* is being obtained at large numbers of ungaged sites where two measurements of flow are made each year for several years; one during high levels of the ground water table and one during low ground water levels. A correlation with concurrent base flow in a nearby gaged stream provides fair estimates of annual minimum and annual average flow in the ungaged streams.

The above 'areal stream gaging' is intended to provide adequate data for general hydrologic studies, for planning and resource conservation studies and for preliminary design of potential water developments. When specific water developments pass from the potential to the probable or firm phase, a complete daily discharge station may be required.

Development of an acoustic flow meter (Milton S. Sachs, Bonneville Power Administration, Portland, Oreg.)—The development of an acoustic flow meter to measure the velocity of a river by sonic or ultrasonic means, was undertaken early in 1957 by the Geological Survey, the Corps of Engineers, and the California Department of Water Resources. The use of such a gage will serve to measure flows of streams affected by tides, by backwater from impoundments or by frequent shifts in control. Developed in cooperation with the Raytheon Corporation, the devices are currently undergoing tests on the Sacramento River in California.

Effect of land-use changes on surface runoff (Aubrey L. Sharp, Agricultural Research Service, Lincoln, Nebr.)—A five-year project begun in May 1957 by the Agricultural Research Service and the Soil Conservation Service of the U. S. Department of Agriculture, and the Bureau of Reclamation of the U. S. Department of Interior has for its primary purpose the development of procedures for evaluating the effects of watershed treatments on the yield of watersheds. Consideration of economics, or the effect of treatment measures on sediment movement or flood peaks will be incidental to the primary purpose. Watershed treatment includes land treatment measures such as changed land use, strip cropping, terracing, and contour farming, and structural measures such as retention and retardation reservoirs and water-spreading systems. Emphasis is being placed on the water-deficient areas of the Great Plains and the Southwest.

Thus far, most of the efforts have been expended in attempting to determine whether or not statistical, graphical, or other means can detect or measure the effects of conservation use and treatment of watershed lands on water yielded by streamflow. A major problem confronting the study is that conservation practices in significant quantities have been applied to most watershed lands only in the last decade or less. Such treatment has, therefore, had only a few years in which to affect water yields. Another major problem concerns estimation of amounts and intensities of precipitation on the watersheds from the relatively sparse network of rain gages in operation. The estimation of rates of streamflow during large floods is also subject to uncertainties. In the subhumid to arid Great Plains and Pacific Southwest, a major part of the total water yield occurs during such times.

The study has confirmed previous research findings that changes in land use and treatment reduce *surface* runoff from research watersheds. The effects, if existent, of the conservation use

and treatment of land on water yielded by streamflow from river basins, varying from a few score to a few thousand square miles in size, have not been found sufficiently large to show up over the variance inherent in the applicable data. No means has yet been found to apply findings from research data to large watersheds.

Use of electronic digital computers in hydrologic studies (Milton S. Sachs, Bonneville Power Administration, Portland, Oreg.,)—A method for using a digital computer for streamflow routing in the Columbia Basin has been developed by D. M. Rockwood, U. S. Army Engineers, Portland, Oregon. In this method water excesses of rainfall and snow melt can be routed by subbasins to synthesize streamflow which in turn is routed through lakes and channels to downstream control points. A new routing technique is made possible by use of the computer.

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Review

MILTON B. DOBRIN, *Introduction to Geophysical Prospecting*, 2nd ed., McGraw-Hill Book Co., New York, 550 pp., 1960, $9.00.

Methods in geophysical prospecting have developed very rapidly during the last decade. It is fortunate, therefore, that the occasion of a second edition provides the author with an opportunity to bring the text up to date. A comparison of this new edition with the first, published in 1952, shows that the author took seriously his responsibility to revise this standard textbook thoroughly. As the author states in the preface, the current literature on exploration geophysics has become so voluminous that it is difficult to keep abreast of new developments. To include all this new material a thorough reorganization as well as the elimination of the whole chapter on well logging was necessary.

Seismic prospecting, as the most important method presently employed, is now treated before, not after, gravitational and magnetic methods. In this section such topics as filter techniques and magnetic recording are given proper treatment; such concepts as wave dispersion are introduced. The complex relationship betwen geophone pattern and shot-point pattern on one hand and the signal to noise ratio on the other hand is now thoroughly discussed on the basis of our present limited knowledge. A whole section on interpretation and geological coordination is added.

In the other chapters on gravitational, magnetic, and electrical methods the revision is not so extensive, but everywhere new material is added. However, the chapter on prospecting for radioactive minerals is completely rewritten. Besides a much better presentation of the elements of radioactivity the chapter includes a description of the scintillation counter which made airborne surveys possible.

The book intentionally restricts the use of mathematics to a very elementary level. However, some of the statements given as a matter of fact could easily be derived even from formulas given in the book. As an example, I note the statement (p. 17) that Poisson's ratio σ can never be greater than 0.5. This fact could be derived, for instance, from formula (2-6) $k = E/3(1 - 2\sigma)$ on p. 18, since $k > 0$.

Some errors that were in the first edition are corrected, but a few obviously have escaped the scrutiny of the author. The rigidity modulus μ is not $E/4 < \mu < E/2$ (p. 18) but $E/3 < \mu < E/2$ as could be derived from formula (2-5). The formula on p. 266, last line, should obviously read $B = \mu \cdot H$. In Figure 13-9, there should be decimal points before the numbers of the ordinates.

The new revision will surely be welcomed by all those who used the book in the classroom or as a brief reference.

Hugo Mandelbaum

List of Recent Books of Interest and Importance to Geophysicists

BENIOFF, H., M. EWING, B. F. HOWELL, JR., AND F. PRESS, *Contributions in Geophysics in Honor of Beno Gutenberg*, Pergamon Press, New York, 244 pp., 1958, $9.00.

BISHOP, MARGARET S., *Subsurface Mapping*, Wiley, New York, 207 pp., 1960, $5.75.

BOLIN, BERT (ed.), *The Atmosphere and the Sea in Motion*, The Rossby Memorial Volume, Oxford Univ. Press, New York, 509 pp., 1959, $15.00.

CLARK, THOMAS H., AND COLIN W. STEARN, *The Geological Evolution of North America*, Ronald Press, New York, 434 pp., 1960, $7.50.

EUROPEAN ASSOCIATION OF EXPLORATION GEOPHYSICISTS, *Geophysical Surveys in Mining, Hydrological and Engineering Projects, 1958*, The Hague, viii + 270 pp., 1959, $4.50.

FAIRLEY, T. C., *Sverdrup's Arctic Adventures*, Longmans, Green, New York, 317 pp., 1960, $6.00.

FIRSOFF, V. A., *Strange World of the Moon*, Basic Books, New York, 236 pp., 1960, $6.00.

FRANCIS, G. E., W. MULLIGAN, AND A. WORMALL, *Isotopic Tracers*, Univ. of London Press; Essential Books, Fairlawn, N. J., 545 pp., 1959, $8.40.

GATLAND, KENNETH W. (ed.), *Project Satellite*, British Book Centre, New York, 169 pp., 1958.

HARRIS, LAWSON P., *Hydromagnetic Channel Flows*, John Wiley, New York, 90 pp., 1960, $2.75.

KING, CUCHLAINE A. M., *Beaches and Coasts*, St. Martin's Press, New York, xii + 403 pp., 1959, $14.50.

KOPAL, ZDENEK, *Figures of Equilibrium of Celestial Bodies*, Univ. of Wisconsin Press, 135 pp., 1960, $3.00.

LANDAU, L. D., AND E. M. LIFSHITZ, *Theory of Elasticity*, Pergamon Press, London, 140 pp., 1959, $6.50 [translated from the Russian by J. B. Sykes and W. H. Reid].

LANG, DANIEL, *From Hiroshima to the Moon*, Simon and Schuster, 496 pp., 1959.

LANGBEIN, WALTER B., AND WILLIAM G. HOYT, *Water Facts for the Nation's Future*, Ronald Press, New York, 288 pp., 1959, $5.00.

MASON, BRIAN, *Principles of Geochemistry*, Second edition, John Wiley, New York, viii + 310 pp., 1958.

MITTERLING, PHILIP I., *America in the Antarctic to 1840*, Univ. of Illinois Press, Urbana, 201 pp., 1959, $5.00.

NETHERLANDS ENGINEERING CONSULTANTS (NEDECO), *River Studies and Recommendations on Improvement of Niger and Benue*, North-Holland Publishing Co. Amsterdam, ix + 1000, 1959, 140 shillings.

ORDWAY, FREDERICK I., III (ed.), *Advances in Space Science*, Vol. I, Academic Press, New York, 424 pp., 1959, $12.00.

OVERMAN, RALPH T., AND HERBERT M. CLARK, *Radioisotope Techniques*, McGraw-Hill, New York, 492 pp., 1960, $10.00.

PRESS, FRANK, L. H. AHRENS, K. RANKAMA, AND S. K. RUNCORN (eds.), *Physics and Chemistry of the Earth*, Pergamon Press, New York, Vol. 3, viii + 464 pp., 1959, $15.00.

SIPLE, PAUL, *90° South*, Putnam's, New York, 384 pp., 1959, $5.75.

SWAINGER, KEITH, *Analysis of Deformation*, Vol. 4, Waves and Vibrations, Macmillan, New York, 370 pp., 1960, $15.00.

WEICKMANN, HELMUT, (ed.), *Physics of Precipitation*, Geophysical Monograph Number 5, American Geophysical Union, National Academy of Sciences, Publication No. 746, xii + 435 pp., 1960, $12.50. (Proceedings of the Cloud Physics Conference, Woods Hole, Massachusetts, June 3–5, 1959.)

WISLER, C. O., AND E. F. BRATER, *Hydrology*, Wiley, New York, 422 pp., 1959, $9.25.

Contents of Bulletin (Izvestiya), Academy of Sciences, U.S.S.R. Geophysics Series, April-August, 1959

Note—The March, 1959, issue of the *Transactions*, pages 28–31, lists the contents of Izvestiya, Geophysics Series for January-September, 1957. The June issue of the Transactions, pages 124 and 125, lists the contents for October-December, 1957. In the September issue, the contents for the first four numbers of 1958 are listed, pages 228–229. In the December 1959 issue, pages 256–259, the contents for the last eight numbers, May-December, 1958, are listed. In the March 1960 issue are listed the contents for the first three numbers of 1959, January-March. Below are listed the contents for the four numbers, April-August, 1959.

The production of the English edition had been undertaken with the aid of a grant from the National Science Foundation starting with the series for 1957. Orders for sets for 1957 ($28.00 for the twelve numbers) and 1958 ($25.00 for the twelve numbers) should be sent to the American Geophysical Union. Individual numbers of either series are available for $5.00 each.

Subscriptions are now being received for the 1959 series. We expect that these twelve numbers will be complete by summer of 1960 and that by the end of 1960 the numbers will be current. However, subscriptions are not yet being accepted for the series beyond 1959. Subscribers to the 1959 series will be notified of plans in this regard as soon as possible.

No. 4, April 1959

On the effective dynamic parameters of nonhomogeneous elastic media during the propagation of a plane longitudinal wave, I. M. Khaykovich and I. A. Khalfin, 11 pp.

The displacement field associated with discontinuities in an elastic medium, A. A. Vvedenskaya, 11 pp.

On the evaluation of accuracy in the determination of the hypocenters of earthquakes, E. V. Glivenko, 11 pp.

The relationships of seismicity and tectonic structure in the Black Sea depression and adjacent areas, A. Ya. Levitskaya and M. V. Muratov, 9 pp.

The calculation of zero point drift during observations on elastic tides, B. P. Pertsev, 2 pp.

The selection of frequency characteristics of filters for seismic signals, F. M. Holzmann, 11 pp.

The use of sound records for distance determination during operations of deep seismic sounding at sea, S. M. Zverev, 10 pp.

On the stability of planetary-scale atmospheric motion, M. B. Galin, 11 pp.

The factor of non-geostrophicity involved in the solution of a three-dimensional problem of the air circumfluent the mountains, G. P. Kurbatkin, 12 pp.

Study on the dispersion of love waves during near earthquakes, S. I. Sikharulidze, 5 pp.

Intermediate and deep-focus earthquakes in relation to the cosmic conditions of the earth, G. P. Tamrazyan, 6 pp.

The shape of elastic pulses accompanying rock breaking, A. G. Konstantinova, 7 pp.

A seismic energometer, V. L. Belotelov, N. V. Veshnyakov, and I. I. Zhilyaev, 6 pp.

Graphical method of calculating the values of the second vertical derivative of the gravity potential, L. V. Dimitrov, 4 pp.

The effect of inhomogeneities in the earth on the field of a rectilinear, infinitely long cable, V. I. Dmitriev, 3 pp.

Determination of the velocity of fall of cloud

drops growing through gravitational coalescence, St. Panchev, 5 pp.
Determining the 'rotation' temperature of hydroxyl in the upper atmosphere, V. S. Prokudina, 4 pp.
On the exchange coefficient in the surface boundary layer of the atmosphere, E. A. Ridel', 3 pp.
The interrelationships of geophysical fields, A. G. Tarkhov, 3 pp.
Chronicle: Second expanded seminar of the seismological and seismic service department, Institute of Physics of the Earth, for the study of surface waves, 3 pp.

No. 5, May 1959

Some spectral characteristics of waves reflected from thin layers, I. S. Berson, 17 pp.
On the dependence of the amplitude of longitudinal head waves, associated with thin layers, from the velocity contrast of the media, N. I. Davydova, 11 pp.
On Love wave observations at the Moscow seismic station and on the structure of the Earth's crust, E. T. Savarensky, O. N. Solov'eva, and B. N. Shechkov, 7 pp.
On the intensity of a wave which has passed through a series of layers with higher velocity I, I. S. Parkhomenko, 9 pp.
Modeling of some geophysical phenomena on electrical grids, B. N. Ivakin, 9 pp.
Study of the compressibility of igneous rocks at pressures up to 5000 kg/cm^2, M. P. Volarovich, D. B. Balashov, and V. A. Pavlogradsky, 10 pp.
Determination of the magnetic stability of rocks under laboratory conditions, G. N. Petrova and V. A. Koroleva, 7 pp.
A physical basis for forecasting wind-generated waves in the ocean, V. V. Shuleikin, 15 pp.
Approximate equations for radiation transfer, K. Ya. Kondrat'ev and I. L. Senderikhina, 7 pp.
On calculating the transformation of air masses in the short-range forecast of nonzonal deviations in heights of absolute topography of an isobaric surface, S. V. Nemchinov, 7 pp.
Heat transfer in a moist dispersed medium, V. P. Deryabin, 5 pp.
The isoline method, Z. Z. Sultanova, 4 pp.
Seismograph system with feedback, B. E. Brunelli and V. V. Alekseev, 4 pp.
The character of the free oscillations of piezo pickups used in modelling seismic phenomena, V. M. Prosvirnin and L. N. Rykunov, 5 pp.
Methods and instruments for the study of the rupture of materials subjected to simple shear, S. D. Vinogradov and K. I. Kuznetsova, 5 pp.
The symmetry type of piezoelectric textures of quartz containing rocks, E. S. Parkhomenko, 7 pp.
On the depth of wind intermixing in the world ocean, V. N. Stepanov, 5 pp.
Contribution to theory of turbulent viscosity in wave motion, S. A. Kitaigorodski, 5 pp.
Forecasting potentialities of empirical influence functions and their properties, P. N. Belov, 5 pp.
On the influence exerted by the magnetic field of the Earth on winds in the ionosphere, V. P. Dokuchaev, 5 pp.
The spectrophotometry of dawn and evening-glow, A. Kh. Darchia, 8 pp.
Optical method for determining the spectrum of the aqueous aerosol particles, G. D. Petrov, 2 pp.
Shape and rate of fall of water and rain drops, A. B. Shupyatsky, 3 pp.

No. 6, June 1959

Resolutions by the XXI Congress of the CPSU and Soviet Science, 3 pp.
The asymptotic behavior of the process of generating an electromagnetic field, A. N. Tikhonov and O. A. Skugarevskaya, 11 pp.
Effective dynamic parameters of elastic media for the propagation of plane transverse polarized waves, I. M. Khaikovich and L. A. Khalfin, 12 pp.
On the intensity of a wave which has passed through a series of layers having an increasing velocity, II, I. S. Parkhomenko, 9 pp.
Hydroxyl radiation in the upper atmosphere, N. I. Federova, 14 pp.
Radiation cooling of stratus clouds, E. M. Feigelson, 11 pp.
Doppler contours and brightness distribution curves for hydrogen in aurorae polares, B. A. Bagaryatsky, 7 pp.
Measurement of the intensity of weak, low frequency magnetic fields in geophysical prospecting, R. Ya. Berkman and V. N. Mikhailovsky, 7 pp.
Construction of dipole and three electrode electro-profiling charts from investigations of straight-line unsymmetric BAMN systems, I. M. Bloch and E. A. Shemyakin, 8 pp.
Determination of the thickness of the Earth's crust from Love wave dispersion observations, E. F. Savarensky and D. E. Sikharulidze, 4 pp.
Microseisms from Lake Issyk-Kul', N. M. Gynkina and S. I. Massarsky, 7 pp.
The Kyren earthquake of August 10, 1958, S. V. Puchkov and R. I. Khovanova, 5 pp.
Methods for determining the elastic parameters of rock specimens, E. I. Bayuk, 3 pp.
The Curie point of rocks with low ferromagnetic content, R. S. Taichinov, 7 pp.
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Spectral studies of the twilight sky in the infrared region, T. G. Megrelishvili, 9 pp.
The air-earth electric convection current, A. M. Izergin, 5 pp.
The effect of temperature of supercooled fogs upon their crystallization by an aerosol of silver iodide, V. N. Balabanova, 6 pp.

Recording of components of radiation balance under vessel conditions, E. F. Babenkov, 3 pp.
Chronicle: The Conference of Nations of the Eurasian Region, February 4–7, 1959, 4 pp.

No. 7, July 1959

The asymptotic behavior of the process of generating an electro-magnetic field in a laminated medium, A. N. Tikhonov, O. A. Skugarevskaya, 9 pp.
The electromagnetic field produced by a dipole at points in distant zones, A. N. Tikhonov, D. N. Shakhsuvarov, 10 pp.
P-waves diffracted at the Earth's core and rigidity of the core, L. N. Rykunov, 9 pp.
The determination of types of reflected multiple waves by their kinematic and dynamic characteristics, A. M. Epinat'eva and N. G. Mikhailova, 19 pp.
Determining a magnitude by excess observations in seismological problems, E. V. Glivenko, 7 pp.
A method for calculating the concentration of the air dose of gamma-radiation in homogeneous geologic media, R. M. Kogan, 7 pp.
The feasibility of using shielded detectors in airborne radiometric prospecting, V. A. Vorob'ev, 8 pp.
Thermal balance of Far Eastern seas, A. M. Batalin, 8 pp.
The methodology of measuring the distribution of snowflakes in snowstorms by sizes, I. V. Litvinov, 7 pp.
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The use of converted waves in the study of the structure of the Earth's crust in the southeastern portions of the main Caucasus range, N. V. Kuz'mina, 12 pp.
Some special features of transverse travel-time curves for refracted waves, M. M. Radzhabov, 6 pp.
Travel time curve of seismic waves of the Caucasus for earthquakes with surface foci, V. G. Papalashvili, 3 pp.
The nature of induced polarization of ion-conducting soils, I. I. Rokityansky, 6 pp.
Theoretical premises of magneto-telluric profiling, M. N. Berdichevsky and B. E. Brunelli, 9 pp.
Some results of experiments conducted with a nuclear magnetometer, A. Ya. Rotstein and V. X. Zierel, 3 pp.
Electrostatic precipitation of aerosol particles from a flow upon large bodies, L. M. Levin, 3 pp.
New methods of recording water drops, F. Ya. Rovinsky, 3 pp.
The influence of the layer of the atmosphere near the Earth on the spread of a heavy homogeneous contaminant originating at a high instantaneous point source, I. L. Karol, 6 pp.
Chronicle: Conference on the results of the research work of the Central Seismological Station 'Pulkovo' and the investigation of surface waves, 2 pp.
Letter to the Editor of the journal 'Bulletin (Izvestiya), Academy of Sciences, USSR, Geophysics Series,' 2 pp.

No. 8, August 1959

Interfering multiple-reflected waves, A. M. Epinat'eva, 14 pp.
The propagation of elastic waves in a layered medium, G. S. Pod'yapol'ski, 10 pp.
Recording of converted refracted $P_1S_2P_1$ waves for the purpose of computing the elastic constants of diabase covered by alluvium, V. N. Nikitin, 15 pp.
Some facts on the character of the velocity change in the upper layers of the Earth's mantle, E. I. Shirokova, 11 pp.
Double refraction in the Earth's mantle, A. V. Vvedenskaya and L. M. Balakina, 9 pp.
Quantitative Geological characterization of the mean gradient of the rate of vertical tectonic movements (dip changes) in the continental crust and some results of its application, M. V. Gzovsky, V. N. Krestnikov, and G. I. Reisner, 14 pp.
The detection of 10-kev electrons in the upper atmosphere by the third Russian sattellite, V. I. Krassovsky, I. S. Shklovsky, Yu. I. Gal'perin, and E. M. Svetlitsky, 7 pp.
Penetration of fast charged particles from the outer atmosphere into the ionosphere, V. D. Pletnev, 3 pp.
A study of light ion spectra in the free atmosphere, L. R. Zwang and N. N. Komarov, 10 pp.
The ultraviolet solar spectrum in the 2636–2937 Å region, V. P. Kachalov, N. A. Pavlenko, and A. V. Yakovleva, 9 pp.
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Observations of short-periodic variations in Earth's electromagnetic field, B. Ye. Brunelli, M. N. Berdichevsky, A. M. Alekseev, and O. A. Burdo (deceased), 10 pp.
Short-period fluctuations of a geomagnetic field, V. I. Afanas'eva, 5 pp.
Paleomagnetic investigations of lower Paleozoic basalts of the Ukraine, A. G. Komarov, 7 pp.
The calculation of the gravitational effects of local inhomogeneities in rocks, V. A. Kazinski, 5 pp.
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On the dependence of the coefficient of horizontal turbulent diffusion in wind-currents upon the relative depth of a water basin, R. V. Ozmidov, 5 pp.

On the properties and nature of spherical seapebbles, A. M. Kuznetsov and V. A. Kuznetsov, 4 pp.

CHRONICLE, Seismological research at some geophysical institutions in the USA, E. V. Karus; Scientific session on the occasion of the 25th anniversary of the Geophysical Institute, Academy of Science of the Georgian S.S.R., A. V. Bukhnikashvili; On some metodological problems encountered during geophysical prospecting for the Poladaura iron ore deposit in the Georgian S. S. R., M. S. Abakelia; Fourth Conference of Young Specialists of the O. Yu. Schmidt Institute of Physics of the Earth of the Academy of Sciences of the U.S.S.R., F. A. Kirillov, 13 pp.

English Translations of Russian Scientific Journals and Papers

Many more translations of Russian scientific writings are available than is generally realized. In order to indicate what is available, the Office of Technical Services of the U. S. Department of Commerce has begun a semi-monthly publication entitled *Technical Translations* which lists translations, not only from the Russian but from other languages as well, available through various organizations in the United States, Canada, Great Britain, and Australia. Some of these are translations in full; others are abstracts of papers in journals, as indicated below. The following information bears on subjects that are likely to be of special interest to geophysicists.

The initials indicate sources from which translations may be obtained as follows: ATS, Associated Technical Services, Inc., P. O. Box 271, East Orange, New Jersey; CB, Consultants Bureau, Inc., 227 West 17th Street, New York 11, New York; DRB, Defence Research Board, Directorate of Scientific Information, "A" Building, Cartier Square, Ottawa, Ontario, Canada; HIG, Hawaii Institute of Geophysics, University of Hawaii, Honolulu 14, Hawaii; LC, Photoduplication Service, Library of Congress, Washington 25, D. C.; MDF, Morris D. Friedman, Inc., Foreign Technical Translations, 67 Reservoir Street, Needham Heights 94, Massachusetts; OTS, Office of Technical Services, Department of Commerce, Washington 25, D. C.; RR, Royer and Roger, Inc., International Division, Washington, D. C.; SLA, SLA Translation Center, The John Crerar Library, 86 Randolph Street, Chicago 1, Illinois; mi, microfilm; ph, photostat.

Asterisk (*) indicates that this item is also available in AGU's cover-to-cover translation of this publication.

ABSTRACT OF PAPERS IN JOURNALS AND COMPLETE JOURNALS

Geodeziya i Kartografiya (Geodesy and Cartography), no. 7, 8, 9, 10, 1959; OTS, $0.60 per copy, $3.50 per six months.

Investigation of clouds, precipitations and thunderstorm electricity; OTS, $0.50 [table of contents of Russian monograph *Issledovaniya Oblakov, Osadkov i Grozovogo Elekrichestrva*, Leningrad, 1957].

**Izvestiya, Akademiya Nauk SSSR, Seriya Geofizicheskaya (Bulletin, Academy of Sciences, USSR, Geophysics Series)*, no. 4, 6 and 7, 1959; OTS, $0.80 per copy, $4.50 per six months. (This volume of this publication is being translated in full by the American Geophysical Union; subscription, $25.00 for the 12 numbers comprising the volume.)

Izvestiya Vysshikh Uchenykh Zavedeniy, Geodeziya i Aerofotos"Yemka (Bulletin of Institutes of Higher Learning, Geodesy and Aerial Photography), no. 2, 3 and 4, 1959; OTS, $0.70 per copy, $4.00 per year.

Meteorologiya i Gidrologiya (Meteorology and Hydrology), no. 8, 9, 10, 1959; OTS, $0.70 per copy, $4.00 per six months.

COMPLETE TRANSLATIONS

ALEKSEYEV, A. P., Oceanographic research by the expedition ship 'Sevastopol'; LC or SLA, mi $1.80, ph $1.80 [*Priroda*, 47, no. 4, 111–112, 1958].

ALEKSEYEV, V. V., A. G. GRAMMAKOV, and others, Radiometric methods in the prospecting and exploration of uranium ores, Book 1; OTS, $6.00 for two books [*Radiometricheskiye Metody Povskov i Razvedki Uranovykh Rud*, Moscow, chap. 1–9, 1957].

ALEKSEYEV, V. V., A. G. GRAMMAKOV, and others, Radiometric methods in the prospecting and exploration of uranium ores, Book 2; OTS, $6.00 for two books [*Radiometricheskiye Metody Povskov i Razvedki Uranovykh Rud*, Moscow, chap 10–16, 1957].

AL'PERT, YA. L., Ionosphere investigations by artificial Earth satellites; LC or SLA, mi $2.70, ph $4.80 [*Priroda*, no. 10, 71–77, 1958].

ARCTIC. SOVIET DRIFTING STATIONS AND EXPEDITIONS 1956–1957; LC or SLA, mi $2.40, ph $3.30; contains five papers as follows: Expeditions of the Arctic Institute in 1957, by V. G. Kanaki; The high-latitude aerial expedition of 1957, by M. M. Nikitin; The end of the drift of station North Pole-4, by L. G. Petrov; 366 days adrift on a floating ice island, by K. A. Sychev; Scientific

inspection of drifting stations and observatories during 1956, by I. M. Dolgin and V. T. Timofeev [*Problemy Arktiki*, no. 4, 103–110, 1958].

BAUM, F. A., S. A. KAPLAN, AND K. P. STANYUKOVICH, Introduction to cosmic gas dynamics; MDF, $2.00 [table of contents and foreword of Russian monograph, Moscow, 1958].

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BOGOROV, V. G., On the 'Vityaz' in the central part of the Pacific Ocean; LC or SLA, mi $1.80, ph $1.80 [*Priroda*, 47, no. 8, 66–73, 1958].

BURYAK, I., Automatic tacheometer; LC or SLA, mi $1.80, ph $1.80 [*Geodezist*, no. 3, 42–45, 1937].

BUZINOV, S. N., On the parameters of similitude at the displacement of one liquid by another and on the influence of flow-rate on the petroleum recovery; LC or SLA, mi $1.80, ph $1.80 [*Izvestiya Vysshikh Uchebnykh Zavedeniy. Neft' i Gaz*, no. 1, 81–85, 1958].

DANILIN, B., Life in cosmos; LC or SLA, mi $2.40, ph $3.30 [*Tekhnika Molodezhi*, 27, no. 7, 34–36, 1959].

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DEMIN, I. D., The influence of the resolution of radar station on the accuracy of determination of ice concentration; LC or SLA, mi $2.40, ph $3.30 [*Problemy Arktiki*, no. 3, 61–67, 1958].

DOBRYSHMAN, YE. M., All-China meteorological conference on long-range weather forecasting; OTS, $0.50 [*Meteorologiya i Gidrologiya*, no. 3, 64–65, 1959].

DOKUCHAYEV, V. P., AND V. I. IVANCHIKOV, Contribution to the theory of motion of ionospheric inhomogeneities and concerning the problem of the reflection of electromagnetic waves from the inhomogeneities of the Epstein-layer type; LC or SLA, mi $2.70, ph $4.80 [*Izvestiya Vysshykh Uchebnykh Zavedeniy, Radiofizika*, no. 1, 34–40, and 150–152, 1958].

DYUBYUK, A. F., Vertical movements in the areas of moving fronts; LC or SLA, mi $2.40, ph $3.30 [*Izvestiya, Akad. Nauk SSSR, Seriya Geofizicheskaya*, no. 9, 1091–1098, 1956].

FEDYNSKIY, V. V., Geophysical research in marine geology; OTS, $0.75 [*Izvestiya, Akad. Nauk SSSR, Seriya Geologicheskaya*, 24, no. 6, 3–15, 1959].

GAL'TSOV, A. P., Analysis of climate-forming processes in application to the genetic classification of fogs; LC or SLA, mi 8.70, ph $30.30 [*Analiz Klimatoo'razuyushchikh Protsessov v Primenenii k Geneticheskoy Klassifikatsii Tumanov*], Moscow, 206 pp., 1957].

GAZARYAN, G. S., A hydraulic investigation of sand incursion during multizone completion; ATS, $8.25 [*Izvestiya Vysshikh Uchebnykh Zavedeniy. Neft' i Gaz*, no. 3, 63–66, 1959].

GOLENCHENKO, A. P., Acoustic sounding for fish from a helicopter; LC or SLA, mi $1.80, ph $1.80 [*Priroda*, 47, no. 4, 79–80, 1958].

GOLOUBKIN, V. N., A. M. Dimaksiyan's 'New telemetering instruments for hydrometeorology,' OTS, $0.50 [*Meteorologiya i Gidrologiya*, no. 3, 57–58, 1959]

GOPTAREV, N. P., On certain characteristics of wind gustiness; LC or SLA, mi $2.40, ph $3.30 [*Meteorologiya i Gidrologiya*, no. 5, 45–49, 1957].

GORSHKOV, V. E., The question of winter fronto- and cyclogenesis in the northern part of the Sea of Okhotsk; LC or SLA, mi. $1.80, ph $1.80 [*Meteorologiya i Gidrologiya*, no. 1, 36–37, 1957].

GRINGAUZ, K. I., Rocket measurements of electron concentration in the atmosphere by means of an ultra-short-wave dispersion interferometer; LC or SLA, mi $1.80, ph $1.80 [*Doklady, Akad. Nauk SSSR*, 120, no. 6, 1234–1237, 1959].

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Notes and Personalia

Notes

• CORRIGENDUM—E. H. Vestine has called attention to three corrections in his paper, *The Survey of the Geomagnetic Field in Space,* in the March 1960 issue of the *Transactions.* On page 4, second column, twelfth line, the word should be 'Measurements' instead of 'Measurement.'

On page 17, in Table 1, column 5, line 6g, the entry should be '+3' instead of '−13.'

On page 21, at the end of the first full paragraph in the first column, add a sentence, 'Bernard C. Byrnes of the U. S. Navy Hydrographic Office will be a participant in the Symposium on the World Magnetic Survey at the Helsinki meeting of the International Association of Geomagnetism and Aeronomy on July 30, 1960. He is scheduled to speak on the topic *U. S. Navy Hydrographic Office Airborne Geomagnetic Survey—Project MAGNET.*'

• NEW EDITION OF MAGNETIC VARIATION CHARTS—The U. S. Navy Hydrographic Office has recently released the new edition of Magnetic Variation Charts for Epoch 1960.0. These charts do not include the data from recent world-wide aeromagnetic surveys of the oceans, but they do reflect the results of extensive survey work over the North Atlantic which was completed several years ago. Project Magnet is proceeding as planned, and it is anticipated that comprehensive data coverage of all the ocean areas will be included in the 1965.0 chart series. Inquiries should be addressed to the U. S. Hydrographic Office, Washington 25, D. C., or any one of the branch offices scattered over the country.

• RELEASE OF BATHYMETRIC DATA—The Navy has recently revised its policy and has made available for the first time all oceanographic sounding data obtained by Navy ships on routine operations using conventional methods of navigation. A very large amount of this material has been accumulated by the Navy over a period of years, yet only a small number of scientists who are working for the Navy and a smaller number of civilian scientists have had access to the material up to the present time. Inquiries regarding this should be sent to the U. S. Navy Hydrographic Office, Washington 25, D. C.

• NEW METEOROLOGICAL SATELLITE—On April 1, 1960, the first television and infrared observation satellite (TIROS I) was launched at Cape Canaveral, Florida. It weighs about 270 pounds and is circling the Earth at an altitude of about 400 nautical miles. The inclination of its orbit is such that it extends about 48° north and south of the equator. The orbital time is about 99 minutes. Its primary purpose is to record pictures of cloud cover by television, taking pictures every 30 seconds for 32 exposures, storing these on magnetic tape, and transmitting on demand to ground stations at Fort Monmouth, New Jersey, and Kaena Point, Hawaii. In addition to the TV cameras, the satellite contains beacon transmitters, attitude sensors, and telemetry circuits. The power is provided by nickel-cadmium batteries charged by solar cells, with an average output of 19 watts. One camera has wide-angle coverage, while the other is a narrow-angle camera to get details of the fine structure of the clouds. The results have been highly succesful and gratifying, as has been indicated by various news reports.

• NEW SOLAR SATELLITE—The United States has placed into orbit around the Sun between the orbits of Venus and the Earth a satellite known as Pioneer V, weighing about 95 pounds and spherical in shape with 'paddle-wheel' solar batteries. The satellite will take 311 days to complete its circuit around the Sun and it will be some five years before it is again in close proximity to the Earth. It is currently speeding away from the Earth at the rate of about one million miles a week. It is the first of the solar satellites that is in orbit within the orbit of the Earth.

• VARIOUS TEACHER-TRAINING SEMINARS OF THE NATIONAL SCIENCE FOUNDATION—The National Science Foundation is again supporting a series of summer seminars and science training programs. Among these the following grants have been made: 57 grants totaling over a million dollars to 54 educational institutions in the interests of research participation for training teachers in science and mathematics. During the summer of 1960 it is expected that under this program 750 teachers will receive training, mostly from secondary schools, with a substantial number from junior colleges and small colleges without research facilities. In addition, approximately half a million dollars in grants have been awarded to 15 colleges and universities for summer institutes for science and mathematics teachers and supervisors of elementary schools. Further grants have been given to aid several thousand secondary school students from all over the nation for summer training in order that they may better determine for themselves whether intellectual and career opportunities exist for them in science, mathematics, and engineering.

A new program is also being initiated for the academic year 1960–1961 to afford out-of-school study to 9000 secondary school science and mathematics teachers. The grants for this purpose total over two million dollars.

• TORNADO FORECASTING OPERATIONS—The U. S. Weather Bureau and the Air Weather Service of the USAF are cooperating in the matter of study and forecasts of tornadoes. The headquarters are located in Kansas City, Missouri, for both as the Severe Local Storm unit of the Weather Bureau and the Severe Weather Warning Center of the Air Weather Service. The area includes almost

half of the area of the continental United States from Albany, Georgia, northward and westward to include most of the United States west of the mountains.

• NEW SERIES OF PUBLICATIONS BY THE SPACE SCIENCE BOARD, NAS-NRC—A new series of publications entitled "Science in Space" has been initiated by the Space Science Board of the National Academy of Sciences. It is contemplated that nine booklets will be released bearing on this subject: Five have already been released as follows: Chapter II, *The Nature of Gravitation*, by R. H. Dicke; Chapter III, *The Earth*, by Harrison Brown, George P. Woolard, Harry Wexler, Alan Shapley, and O. G. Villard, Jr.; Chapter IV, *The Moon*, by Harold C. Urey; Chapter V, *The Planets*, by Harold C. Urey; Chapter VII, *Physics of Fields and Energetic Particles in Space*, by J. A. Simpson (ed.), E. N. Parker, James A. Van Allen, and J. W. Chamberlain. The two publications entitled *The Moon* and *The Planets* summarize current views regarding these, outline areas of uncertainty and controversy, and state the facts that seem to be well established. One of the big questions presented in *Physics of Fields and Energetic Particles in Space* is "How do electromagnetic fields originate in stars and space and speed up particles to such high energies that auroras, cosmic radiation, and similar phenomena result?"

• COMMITTEE ON SPACE RESEARCH—The First International Space Science Symposium was held at Nice, France, in January sponsored by the International Committee on Space Research (COSPAR). An agreement was reached with regard to details of the organization at the time of the meeting in Nice. This group operates within the framework of the International Council of Scientific Unions. Its work parallels the United Nations Outer Space Committee on the peaceful uses of outer space which is actively working on the political problems involved.

• FURTHER DATA ON 45,000-MILE EARTHQUAKE ZONE—Scientists of Columbia University are compiling new evidence on the significance of the world-wide system of ocean-bottom cracks which coincide with an active earthquake zone along its 45,000-mile length. The securing of new data is by means of the 'thermograd' which is an ocean-floor probing device containing an electrical recording instrument to which heat-sensitive wires are attached. The story concerning this appeared in the February 1960 issue of *Harper's Magazine*. Recent soundings made by the research vessel *Vema*, now on a 12-month scientific cruise that will circumnavigate Antarctica, indicate that the deep cracks in the beds of the Atlantic and Indian Oceans join south of the tip of Africa.

• NEW SEISMOLOGICAL OBSERVATORY AT RENSSELAER POLYTECHNIC INSTITUTE—Construction work is under way for a new seismological observatory at Rensselaer Polytechnic Institute, the unit to be a part of the nationwide earthquake monitoring network of the U. S. Coast and Geodetic Survey.

• RECORD DESCENT OF BATHYSCAPHE—The Navy's bathyscaphe *Trieste* descended last January in the Marianas Trench to a depth of over 37,000 ft, one of the greatest depths in the oceans of the world. This is the bathyscaphe that was designed and constructed by Auguste and Jacques Piccard, father and son. One of the two aboard the vessel was Jacques Piccard.

• NSF GRANTS FOR PHYSICS-CHEMISTRY INTERDISCIPLINARY STUDY—The National Science Foundation has recently given two grants totaling nearly $600,000 for an interdisciplinary study in chemical and solid state physics to be conducted at the Massachusetts Institute of Technology. One phase of the work will involve the nature of various low-temperature phase transitions, such as changes in crystal structure, and a second phase will include a study of crystallographic and magnetic phenomena in selected materials with a polarized beam neutron spectrometer.

• THEODORE VON KARMAN MEDAL ESTABLISHED—The Theodore Von Karman Medal has been endowed and established by the Engineering Mechanics Division of the American Society of Civil Engineers. The Medal will be awarded to an individual in recognition of distinguished achievement in engineering mechanics applicable to any branch of civil engineering.

• KITT PEAK NATIONAL OBSERVATORY DEDICATED—The new Kitt Peak National Observatory, located near Tucson, Arizona, was dedicated on March 15, 1960. The Observatory is available to all qualified astronomers of the United States and is the optical equivalent of the National Radio Astronomy Observatory at Green Bank, West Virginia. Both are supported by the National Science Foundation. In the case of the Kitt Peak Observatory, the support is through AURA (Association of Universities for Research in Astronomy) which includes the universities of California, Chicago, Harvard, Indiana, Michigan, Ohio State, Princeton, Wisconsin, and Yale. Aden P. Meinel is the director.

• WORK OF ARCTIC STATION NUMBER II—Early in January it was necessary to abandon drifting ice station Number II because of the breakup of the ice floe. During the interval that this station was in operation a great amount of scientific work was accomplished, including charting of a hitherto unknown submerged island, photographing for the first time portions of the floor of the Arctic Ocean which revealed strange 'chicken tracks' 7000 ft below the flowing ice. In addition, the Columbia team established radio contact with the South Pole. It gathered a great deal of data drifting within 300 miles of the North Pole and collected new scientific material in the fields of oceanography, seismology, gravity, and geomagnetism. The station was originally established in March 1957. That floe broke up in November 1958, and the second floating station, namely, Alpha II, was established in May 1959.

• NEW SEAMOUNT IN THE SOUTH ATLANTIC—An uncharted seamount or submerged island rising some 16,000 ft above the ocean floor has been discovered 550 miles west of the Cape of Good Hope by scientists of Columbia University. The seamount appears to be an extinct volcanic cone, 35 miles across at the base and five miles across at the top. Its top is covered with coral and kelp, and it is associated with a large anomaly in the Earth's magnetic field. It lies about 150 miles west of a similar seamount, suggesting that a new line of ancient volcanism has been found.

• ARCTIC WEATHER FLIGHTS—The Air Weather Service has announced that at the close of February 1960 they had completed the 3000th weather reconnaissance mission over lonely Arctic wastes, involving nearly 10 million miles during the last 13 years. This is only a part of the Air Weather Service's reconnaissance over remote areas, others operating out of Bermuda, Guam, Japan, and California.

• NEW FELLOWSHIPS FOR INTERNATIONAL STUDIES—The Organization for European Economic Co-operation and the National Science Foundation recently announced the establishment of senior visiting fellowships under the sponsorship of the OEEC under the administration of the National Science Foundation. These fellowships are intended to assist scientific and technical institutions to incorporate more quickly into their own advanced teaching and research programs the most recent developments from all over the world. Institutions may send their senior scientists, mathematicians, and engineers to study new developments in techniques at advanced research and educational institutions chiefly of the member countries of the OEEC. Fellowships are given for intervals ranging from eight weeks to six months but under special circumstances may be extended to a year. Any public or publicly supported scientific or technical institution or any private training or research institution of a non-profit character in the United States may nominate candidates for the fellowships. Those coming from the United States must be citizens of the United States with full professional standing in their fields, with at least five years of experience in research, teaching, or other relevant professional work. They must also have the necessary linguistic abilities for learning and profitable discussion in the countries they propose to visit. The fellowships will carry no stipend but fellows will receive a subsistence allowance and air-tourist transportation. They will be eligible to receive their regular salaries or appropriate allowances provided for or approved by their nominating institutions. Details should be secured from the Fellowship Office, National Academy of Sciences—National Research Council, 2101 Constitution Avenue, N.W., Washington 25, D. C.

• REDUCTION IN ACTIVITY OF KILAUEA VOLCANO—Kilauea Volcano, which started erupting in early October 1959 and continued with increasing violence into the winter months, has now greatly lessened. The collapse of Halemaumau, a large pit in the floor of the volcano, has greatly lessened the pressure of lava and lava flow, and the steam pressure has subsided. This change occurred quite abruptly during the early morning hours of February 7, 1960, extending over an area 1000 ft in diameter within a few hours and deepening to 200 ft within 10 minutes.

• BRITISH WORK IN ANTARCTICA CONTINUES—The British replacement party, under Sir Vivian Fuchs who crossed Antarctica last year, recently sailed from Uruguay. The group includes 27 scientists who will undertake the restoration of the base at Stonington Island and relieve five other British winter stations along a 2000-mile coastal area of Antarctica.

• TETHYS EXPEDITION OF THE SCRIPPS INSTITUTION OF OCEANOGRAPHY—In the interval from June 15 to August 23, 1960, the *Spencer F. Baird* will undertake an expedition to the central and equatorial Pacific in the area lying between Hawaii and the American continent. The purposes are biological and geological as well as geophysical. On the mid-ocean portions an extensive bottom coring program will be carried out to the south of Hawaii.

• CONTINUED GRANTS OF THE SHELL COMPANIES FOUNDATION—The Shell Companies Foundation has allotted almost a million and a half dollars in 1960 for educational, charitable, religious, and public service organizations. These include Shell Merit Fellowships given each year to 100 outstanding high school teachers of science and mathematics to attend summer seminars and Shell Merit Scholarships which are given each year to 25 high school students who plan careers as teachers of high school chemistry, physics, general science, and mathematics. The number of educational institutions receiving grants has been increased from 43 to 53, the grants being used for fellowships in post-graduate work and research. Details concerning the program may be secured from Shell Companies Foundation, 50 West 50th Street, New York 20, New York.

• COUNCIL FOR THE ADVANCEMENT OF SCIENCE WRITING—The National Association of Science Writers has announced the organization of a Council for the Advancement of Science Writing, the purpose of which is to improve the standards for science writing and to stimulate an increase in the quality of science news carried by all media of mass communication. Earl Ubell, Science Editor of the New York Herald Tribune, is President of the Council.

• NEW ARID LANDS NEWSLETTER—A new bulletin entitled *Arid Lands Research Newsletter* is being published by the Committee on Desert and Arid Zones Research of the Southwestern and Rocky Mountain Division of the AAAS. News items and inquiries should be sent to the Editor, Richard B. Woodbury, Department of Anthropology, University of Arizona, Tucson, Arizona.

• OCEANOGRAPHIC EXPLORATION AROUND THE SWAN ISLANDS—The Swan Islands, about 100 miles

northeast of Honduras in the Caribbean and near the precipitous depths of the Cayman Trough, are under new study by the Coast and Geodetic Survey in connection with the recent visit to the islands for the purpose, in part, of census taking. The shelf and surrounding sea are being studied, sea waters and sediments are being sampled, and the flora and fauna of the waters photographed. A Weather Bureau station is maintained on Great Swan and the Civil Aeronautics Administration maintains an airways beacon.

• INTERNATIONAL SYMPOSIUM ON ARCTIC GEOLOGY —The first International Symposium on Arctic Geology was held in Calgary, Alberta, Canada, in January 1960. A number of scientists from the United States took part, and the exhibits included one on the physiographic provinces of Alaska utilizing aerial photographs and up-to-date topographic maps.

• NEW THEORY ON BLUE HAZE—The blue haze seen so commonly over the world's vegetated areas may be caused by asphaltic and bituminous particles created by hundreds of millions of tons of volatile hydrocarbons and near-hydrocarbons released into the atmosphere by living plants. These rain down on the earth and possibly in time may form petroleum. The theory is set forth in a paper by Frits W. Went in a recent issue of the *Proceedings of the National Academy of Sciences.*

• CERTIFICATION OF CONSULTING METEOROLOGISTS —The American Meteorological Society has recently adopted a policy of establishing a list of Certified Consulting Meteorologists. The investiture of the first 22 of these was undertaken at the recent meeting of the Society in Boston. It has also established a Seal of Approval for radio and television broadcasters of weather.

• NATIONAL ACADEMY OF SCIENCES SENDS SCIENTIFIC COOPERATION MISSION TO ASIA—The National Academy of Sciences has sent Farrington Daniels and Ralph E. Cleland on a four-month mission to eleven Asian countries in the interests of developing effective cooperation in science and technology. Harold J. Coolidge, Executive Director of the Pacific Science Board, will accompany them on part of the trip. They will explore with Asian scientific leaders how the development of their countries can most effectively be furthered by science and technology. The study is being made under the joint auspices of the National Academy and the Asia Foundation and will include visits to Pakistan, India, Burma, Thailand, Malaya, Indonesia, the Philippines, Viet Nam, Republic of China (Taiwan), Republic of Korea, Japan, Singapore, and Hong Kong.

• DO-IT-YOURSELF WEATHER BRIEFING SYSTEM—A weather briefing system for pilots has been introduced at Laurence G. Hanscom Field at Bedford, Massachusetts, providing a self-briefing display. Six units are involved in the display giving up-to-the-minute reports of current weather and weather forecasts over the eastern half of the United States. The self-briefing display consists of six separate sections covering the area east of the Mississippi River. The six parts are the synoptic display, areas of severe weather, military terminals, civilian terminals, winds aloft, and special data on the local terminal.

Personalia

• HENRY R. ALDRICH, since 1940 Secretary, Councilor, and Editor-in-Chief of the Geological Society of America, has retired after 25 years with the Society. He has joined the staff of the Lamont Geological Observatory at Palisades, New York.

• CARL I. ASLAKSON, Consultant for Aero Service Corporation, has been awarded the Boyden Premium, a $500 prize, by the Franklin Institute of Philadelphia "in consideration of his contribution to the measurement of the speed of radiation in space through the use of Shoran technique and thereby as the first American to aid in establishing a new and significantly more nearly accurate value of 16 km per second higher than the long accepted value."

• WILLIAM H. BIERSCHENK, Geological Engineer at the Hanford Atomic Product Operation plant of General Electric Company, has joined the Frank E. Basil Company, Inc., as Office Engineer and Principal Geohydrologist in their Iranian office.

• J. A. B. BJERKNES of the University of California and ERIK PALMEN of the University of Helsinki have recently been named the recipients of the Carl-Gustaf Rossby Award of the American Meteorological Society for outstanding research contributions.

• HARRY F. BLANEY, irrigation engineer with the U. S. Department of Agriculture in Los Angeles, has returned from a five-month inspection tour of irrigated areas in Greece, Turkey, Israel, Pakistan, India, Thailand, Japan, and Hawaii. In Israel he spent three months evaluating irrigation research and water utilization for the U. S. International Cooperation Administration.

• CHARLES L. BRETSCHNEIDER, Hydraulic Engineer in the Research Division of the Beach Erosion Board, has been awarded the ASCE Research Prize for 1959 "in recognition of an outstanding contribution to the knowledge of coastal engineering."

• NORMAN H. BROOKS of California Institute of Technology has been awarded an ASCE Research Prize for 1959 "in recognition of an outstanding contribution to the knowledge of the mechanics of alluvial streams."

• STEVENSON BUCHAN, Chief Geologist of the Water Division of the Geological Survey and

Museum, London, has recently been in the United States on a lecture tour that included a swing from the east coast and back.

• ROBERT C. BUNDGAARD, Lt. Col., USAF, has recently been elected a councilor of the American Meteorological Society for a three-year term.

• HORACE R. BYERS of the University of Chicago has recently been named the recipient of the Charles Franklin Brooks Award for outstanding service to the American Meteorological Society.

• ARTHUR CASAGRANDE, Professor of Civil Engineering at Harvard University, has been awarded an ASCE Research Prize for 1959 "in recognition of an outstanding contribution to basic research in soil mechanics and foundation engineering."

• THEODORE K. CHAMBERLAIN of Scripps Institution of Oceanography has recently received a grant for the study of Sagami, Suruga, and Toyama submarine canyons off the coast of Japan, working with Dr. Hiroshi Niino of Tokyo Suisan Daigaku. The work will be undertaken over a two-year interval starting in 1960.

• HAROLD COOLIDGE, Executive Director of the Pacific Science Board of the National Academy of Sciences, has been made an officer of Monisaraphon, an order of merit for literary and scientific services of the Government of Cambodia.

• EARL G. DROESSLER, Program Director for Atmospheric Sciences, National Science Foundation, has recently been elected a councilor of the American Meteorological Society for a three-year term.

• ALAN J. FALLER, Research Associate in Meteorology at Woods Hole Oceanographic Institution, has taken up a year's studies at the International Meteorological Institute at Stockholm under a Guggenheim Fellowship.

• ROBERT G. FLEAGLE of the University of Washington has recently been given the Meisinger Award of the American Meteorological Society. The award was made in 1959, but the bestowal was made only recently because of his absence from the country.

• WILLIAM V. KIELHORN, formerly ONR Project Officer at Woods Hole Oceanographic Institution, has accepted a position as Staff Engineer in oceanography with Lockheed Aircraft Corporation in Burbank, California, working with the Lockheed Antisubmarine Warfare Systems Organization.

• GERARD P. KUIPER, formerly of Yerkes Observatory, has been named Research Professor in the Institute of Atmospheric Physics of the Steward Observatory of the University of Arizona.

• WILLIAM LITTLEWOOD, Oceanographer of the Navy Hydrographic Office, has been appointed Deputy Science Officer with the American Embassy in Stockholm.

• THOMAS F. MALONE, Director of Research for the Travelers Insurance Companies and President of the Section of Meteorology, AGU, has been elected President of the American Meteorological Society for a two-year term.

• GEORGE B. MAXEY of the Illinois State Geological Survey has completed a lecture tour for the American Association of Petroleum Geologists during which he spoke to about 50 geological societies and several universities in the United States and Canada. He lectured on the subject "The geology water and its importance to our industrial civilization."

• GERALD T. MCCARTHY, partner of Tippetts-Abbett-McCarthy-Stratton, Consulting Engineers, has been elected Vice President of the American Institute of Consulting Engineers.

• CHARLES B. MOORE of Arthur D. Little, Inc., has recently been cited by the American Meteorological Society for the part he took in the recent high-altitude balloon flight made for the purpose of studying the planet Venus.

• JEROME NAMIAS, Chief, Extended Forecast Section, U. S. Weather Bureau, has recently been elected a councilor of the American Meteorological Society for a three-year term.

• DONALD R. PATCH, formerly Meteorologist at the U. S. Naval Station, Roosevelt Roads, Puerto Rico, has been appointed Ship Routing Forecaster for the Optimum Track Ship Routing Program with the U. S. Fleet Weather Facility, U. S. Naval Air Station, Alameda, California.

• LOUIS C. PELTIER has left his post as Technical Director, Special Projects Staff, Office of Area Development of the Department of Commerce, to become Head of Regional Economics Studies at Midwest Research Institute in Kansas City.

• D. F. PETERSON, Dean of the College of Engineering at Utah State University, served as senior leader of a seminar on irrigation practices under joint sponsorship of the International Cooperation Administration and the government of Pakistan. Representatives of the countries of the Near East and south Asia met in Lahore, Pakistan, the last two weeks of February.

• ROBERT H. RANDALL of the Bureau of the Budget will retire July 1, 1960 after about 25 years of federal service. He will become Vice President of Aeroservice Corporation following his retirement from government work.

• DANIEL F. REX, Officer in Charge of the Navy Weather Research Facility at Norfolk, Virginia, is being loaned by the Navy Department to serve for an extended period as Assistant Chief of the Weather Bureau for the Development of Technical Services, in addition to his regular Naval duties.

• WALTER ORR ROBERTS, Director, High Altitude Observatory, University of Colorado, has recently been elected a councilor of the American Meteorological Society for a three-year term.

• MILTON S. SACHS, Bonneville Power Administration hydraulic engineer for the Department of Interior, spent six weeks in Ethiopia at the end of 1959 as a consultant to the United Nations Special Fund, making a water resources survey of the Awash River valley to determine the potential of flood control, irrigation, and other beneficial water uses.

• THORNDIKE SAVILLE, JR., Chief, Special Project Branch, Research Division of the Beach Erosion

Board, Washington, D. C., has received the National Capital Award for outstanding contributions by a young engineer from the D. C. Council of Engineering and Architectural Societies and the Washington Academy of Sciences.

• PAUL B. SEARS, Chairman of the Conservation Department of Yale University, will retire on June 30, 1960

• S. FRED SINGER, Professor of Physics at the University of Maryland, has been designated by the U. S. Junior Chamber of Commerce as one of the outstanding young men of 1959 for his work on the theory of the Earth's radiation belts and the measurement of ionospheric electrojet currents.

• JEROME SPAR of the Department of Meteorology and Oceanography, New York University, has recently been elected a councilor of the American Meteorological Society for a three-year term.

• GLENN E. STOUT, Head of the Meteorology Section of the Illinois State Water Survey, has been named Chairman of the newly formed Section of Meteorology of the Illinois State Academy of Science.

• LORENZ G. STRAUB, Director of the St. Anthony Falls Hydraulic Laboratory of the University of Minnesota, has been named an honorary member of the International Association for Hydraulic Research.

• JAMES S. SWEET, staff hydrologist of the U. S. Weather Bureau, Washington, D. C., has returned from a trip to South America where he evaluated proposed hydrometeorological networks in Chile and Ecuador for the United Nations Special Fund.

• HAROLD E. THOMAS, Research Geologist with the Ground Water Branch of the U. S. Geological Survey, is on a two-year assignment with the International Cooperation Administration in Tunisia to develop a ground-water organization.

• PARKER D. TRASK of Berkeley, California, presented a lecture on January 28, 1960, to a joint meeting of the Geophysical Society of Hawaii and the Hawaiian Academy of Science. The lecture was entitled "Peace-time Uses of Underground Nuclear Explosions."

• THEODORE VON KARMAN of the California Institute of Technology has recently been awarded honorary membership in the Meteorological Society.

• HARRY W. WELLS of the Carnegie Institution of Washington has accepted an appointment with the State Department for duty as Science Officer at the American Embassy in Rio de Janeiro.

• ACADEMICIAN I. P. BARDIN, Vice President of the U.S.S.R. Academy of Sciences, died suddenly on January 7, 1960, at the age of 76.

• ARTHUR LOUIS DAY, retired Director of the Geophysical Laboratory of the Carnegie Institution of Washington, died March 2, 1960, at the age of 90. He was born in Brookfield, Massachusetts, and took his baccalaureate degree from Yale in 1892 and his Ph.D. from the same university in 1894. He also has received honorary doctorates from Groningen, Columbia, Princeton, and University of Pennsylvania. From 1894 to 1897 he was Instructor in Physics at Yale University, and from 1897 to 1900 was a member of the scientific staff of Physikalisch-Technische, Reichanstalt, Charlottenburg, Germany. He served with the U. S. Geological Survey during the interval 1900–1906, in the latter year became the first Director of the Geophysical Laboratory of the Carnegie Institution of Washington, a post which he held until his retirement in 1936. He had been Vice President of Corning Glass Works since 1919, a member of the National Academy of Sciences since 1913, and a member of the Academy of Science of Norway, Sweden, and the U.S.S.R. He was the Second Recipient of the William Bowie Medal of AGU in 1940, and numbered among other awards the John Scott Medal, 1923; the Roozeboom Medal of the Royal Academy of Science in Amsterdam, 1939; the Wollaston Medal of the Geological Society of London, 1941; and the Penrose Medal of the Geological Society of America, 1947. He was one of the original members of the American Geophysical Union and served as its Vice President during the years 1922–1924, as well as President of the Section of Geophysical Chemistry from 1920 to 1922, a section which was discontinued in 1924.

• STERLING PRICE FERGUSSON, Research Fellow of Harvard University's Blue Hill Meteorological Observatory, retired, died November 26, 1959, at the age of 92. Born in Dixon's Spring, Tennessee, he attended the Haywood Academy in Tennessee from 1878 to 1887, in which year he became Assistant Meteorologist at the Blue Hill Observatory. From 1911 to 1916 he served as Professor of Meteorology and Associate Meteorologist for the Experiment Station at the University of Nevada. In 1916 he took up duties with the U. S. Weather Bureau in Washington, D. C., as meteorologist in charge of the testing laboratory, a post which he held until 1931. In 1931 he became Research Fellow at the Harvard University Blue Hill Meteorological Observatory, where he remained until his retirement in 1948. He was a member of the Hoobs Greenland Expedition during the years 1926–1928. He had been a member of AGU since 1930.

• OMAR O. FICKEISSEN, Meteorologist and Lieutenant-Colonel in the Air Corps Reserve, died October 12, 1959, at the age of 40. He was born in St. Louis, Missouri, and attended Rubicam Business College, General Motors Institute of Technology, and Massachusetts Institute of Technology. He served for a brief period from 1941 to 1942 with General Motors, then joined the Air Corps as Weather Officer, a post which he retained until 1945. He remained in the service of the Air Corps as a civilian meteorologist until the time of his death. He had been a member of AGU since 1950.

• BENO GUTENBERG, world-renowned specialist in seismology and other aspects of geophysics died

January 25, 1960, at the age of 70. He was born in Darmstadt, Germany, June 4, 1889, took a degree from the Technical Institute of Darmstadt in 1928 and his doctorate from the University of Goettingen in 1911. He has subsequently received a number of honorary doctorates. His early years were devoted to study of various problems of Earth physics. In 1930 he came to the United States and took up duties as Professor of Geophysics at the California Institute of Technology and for a number of years served as Director of the Seismological Laboratory of the Institute. He was instrumental in reorganizing the former Association of Seismology of the IUGG which in 1951 became the Association of Seismology and Physics of the Earth's Interior with Dr. Gutenberg serving as its first President. He was the recipient of many awards and medals, and in 1953 he was named the Fifteenth Recipient of the William Bowie Medal. He became a member of AGU in 1932 and a life member at the beginning of the current year.

• Robert Lee Lowry, Consulting Surface Water Hydrologist of Austin, Texas, died May 31, 1959, at the age of 59. He was born in Waxahachie, Texas, and attended Trinity University there, receiving his baccalaureate degree in 1922. During the early part of his career he devoted considerable time to work for the Texas Reclamation Department and subsequently went into the service of the U. S. Bureau of Reclamation. He served for ten years with the International Boundary Commission with reference to work chiefly on the Rio Grande. In 1948 and 1949, he undertook work with the State Department in Venezuela and subsequently on the Hillyman River Commission in Asia. He had been a member of AGU since 1936.

• Charles Stevens Partridge, weather consultant, forecaster, and writer since 1925, died September 1, 1959, at the age of 80. Born in Selma, Alabama, he attended the University of the South, securing his baccalaureate degree in 1899. In 1918, he attended Columbia University's U. S. Navy Gas Engine School. From 1942 to 1943 he was Instructor in Meteorology at the Merchant Marine School, Seamen's Church Institute, New York. Since 1946 he had been a Weather Consultant with radio station WOR in New York. He had been a member of AGU since 1948.

• Caleb Mills Saville, for many years manager of the Water Bureau of the Metropolitan District of Hartford, Connecticut, died February 14, 1960, at the age of 94. He was born in Melrose, Massachusetts. He took his baccalaureate degree at Harvard in 1889 and continued in graduate studies for an additional year. The first twenty years of his career he devoted to various engineering tasks in the Boston area and the Panama Canal. He undertook duties with the Water Bureau in Hartford in 1912. He became a member of the American Geophysical Union in 1932 and had been a life member for several years. He was well known for his outstanding contributions to literature, especially as it relates to water problems. It should be noted that the Saville family is the only one in which three generations were represented in the membership of the American Geophysical Union. His son, Thorndike Saville, and his grandson, Thorndike Saville, Jr., are both members.

• Abraham Streiff, Consulting Engineer of Jackson, Michigan, died January 4, 1960, at the age of 79. He was born in Java and took his baccalaureate degree at the Technologic Institute in Delft, The Netherlands, in 1901. He subsequently did graduate work at the Federal Polytechnikum in Zurich, also serving as an Assistant in Hydraulic Engineering from 1904 to 1907. For 30 years he was engaged in the design of hydroelectric plants throughout the United States as well as in Mexico, Brazil, Spain, and Liberia for the Fargo Engineering Company in Jackson, Michigan. He also served for a time as Vice President of the Ambursen Engineering Company. Since 1952, he had been Hydraulic Consultant for the American Smelting and Refining Company. He had been a member of AGU since 1933.

Union, Section, and Committee Activities

Forty-First Annual Meeting (1960)

Minutes, General Assembly and Section Meetings

NAS-AGU Symposium on Solar Emissions and the Interplanetary Medium

This symposium was part of the Annual Meetings of the National Academy of Sciences and the American Geophysical Union, sponsored by the U. S. National Committee for the IGY, the Planning Committee on Planetary Sciences of the AGU, and the U. S. National Committee for URSI. Support was provided by the National Science Foundation, and the symposium was arranged by Alan H. Shapley (Chairman), R. Grant Athay, Herbert Friedman, and Robert Jastrow. Two sessions were held in the Great Hall of the National Academy of Sciences on the afternoon of April 27 and the morning of April 28. About 300 persons attended each of the sessions.

There were four papers in each session, as follows:

FIRST SESSION
(ROBERT JASTROW, *Chairman*)

(1) ARNULF SCHLÜTER AND L. BIERMAN: Solar Corpuscular Emissions and the Interplanetary Medium
(2) D. E. BLACKWELL: Interplanetary Electron Densities
(3) J. H. PIDDINGTON: Interplanetary Magnetic Fields
(4) JOSEPH W. CHAMBERLAIN: Properties of Interplanetary Gas

SECOND SESSION
(WALTER O. ROBERTS, *Chairman*)

(5) J. F. DENISSE: Interpretation of Type IV Radio Bursts
(6) HERBERT FRIEDMAN: Survey of Observations of Solar Ultraviolet and X-Rays
(7) G. ELWERT: Theory of X-Ray Emission
(8) R. GRANT ATHAY: Sources of Ultraviolet Emission

Smoker

The Smoker was held in the Grand Ball Room of the National Press, Club, National Press Building, 14th and F Streets, N.W., Washington, D. C., on the evening of Thursday, April 28, 1960. Over 500 were in attendance. This gathering was purely informal and provided pleasant opportunities for those in attendance to meet old friends and to make new acquaintances. There was an ever shifting population at the various tables and nooks and undoubtedly affairs of considerable importance were initiated or progressed markedly.

General Assembly: Papers on Antarctic and Business Meeting

The General Assembly was called to order by Harry Wexler, who served as Chairman of the scientific portion of the business session, at 14h 00m on Friday, April 29, 1960, in the Great Hall of the National Academy of Sciences. After an appropriate introductory statement, the following program was presented:

(1) MORTON J. RUBIN: Antarctic Meteorology —A Review of Current Concepts
(2) ALBERT P. CRARY: Ice Cover of Antarctica
(3) CHARLES R. BENTLEY: Sub-Glacial Structure of Antarctica

About 200 were in attendance. There was brief discussion following each paper. Aften a ten-minute recess, the Business Meeting was called to order by President Berkner at 16h 00m.

The minutes of the Business Meeting of the Fortieth Annual Meeting (see *Trans.*, vol. 40, pages 138–142, 1959) were approved.

SUMMARY REPORT BY THE GENERAL SECRETARY

General Secretary Sayre briefly reviewed the reports that appear in full in the *Transactions* in connection with the meetings of the Executive Committee. One, for the first half of this interval, appeared in the March 1960 issue of the *Transactions*, pages 54–58. The report for the second half will appear in the September 1960 issue of the *Transactions*. He noted that the net membership growth in the past 12 months had been about 430 members, and read the names of the members who had died during this interval and whose names appear in the reports above cited.

REPORT OF THE PRESIDENT

President Berkner noted the hard work that has been done by J. W. Joyce in preparation for the Twelfth General Assembly of the IUGG in Helsinki, and the meeting of the Academy delegates to be held in the Board Room of the Academy on April 30, for briefing purposes. It was noted that it appears as though some 300 to 400

delegates will be in attendance from the United States.

Thanks were extended to Meetings Chairman Abelson and to the Executive Secretary for the arrangements for the Annual Meeting, then nearing completion, and to the Secretaries and Program Chairmen for the important part they had taken.

Reports of Standing Committees

Meetings Chairman Abelson noted that in 1961 the National Academy will presumably meet April 24–26, 1961 and recommended that we meet on April 19 to 22 in the preceding week.

Reports of Special Committees

Tellers—Chairman James N. Jordan reported as follows:

The Committee of Tellers met at the office of the American Geophysical Union at 09h 30m on March 24, 1960, to pass on and count the ballots concerning the amendment of Article 3 of the Statutes by adding paragraph (g) as follows:

(g) *Supporting members*—Corporations, other organizations, and individuals interested in geophysics and desirous of supporting the Union may become members under the following classifications upon election by the Executive Committee of the Union and payment of the annual sums indicated: Contributing Members, $500; Sustaining Members, $1000; Benefactors, $5000. Each Supporting Member and the designated representative of the corporation or other organization Supporting Member shall enjoy the privileges of a Member.

The ballots were as follows:

Total ballots received		1871
For the amendment		1812
Against amendment		46
Foreign	8	
Unmarked, or intent of voter not clear	5	
Defective	13	
Qualified ballots		1858

It is well to point out that several ballots raised the question that possibly the individual supporting members may designate more than one representative for each corporation rather than one representative for each corporation as we understand was the intent of the Executive Committee.[1] However, the plurality of the voting seems to be decisive.

The members of the Committee of Tellers who participated in the meeting were: James F. Lander, Robert B. Guillou, Howard W. Oliver, B. W. Seaton, and James N. Jordan, Chairman.

[1] By action of the Executive Committee on April 25, 1960, this intent was confirmed and the statement of the amendment as set forth above has been edited to clarify this intent.

Resolutions—Chairman Helmut Landsberg presented the following resolutions which were unanimously approved:

(1) Resolution of Thanks for the Use of Facilities for the Regional Meeting at Corvallis, Oregon

Whereas, The success of the Pacific Northwest Regional Meeting at Corvallis, Oregon, November 5–6, 1959 was due in large part to the space and facilities generously provided by the Oregon State College, therefore be it

Resolved, That the American Geophysical Union express its great appreciation to the Oregon State College for the use of its meeting rooms and other facilities, and request the Executive Officer of the National Academy of Sciences to express the thanks of the Union to the appropriate official of the Oregon State College.

(2) Resolution of Thanks for the Use of Facilities for the Regional Meeting at the University of Southern California

Whereas, The success of the Pacific Southwest Regional Meeting at Los Angeles, California, February 4–5, 1960 was due in large part to the space and facilities generously provided by the University of Southern California, therefore be it

Resolved, That the American Geophysical Union express its great appreciation to the University of Southern California for the use of its meeting rooms and other facilities, and request the Executive Officer of the National Academy of Sciences to express the thanks of the Union to the appropriate official of the University of Southern California.

(3) Resolution of Thanks for the Use of Facilities for the Forty-First Annual Meeting

Whereas, The District of Columbia Chapter of the American Red Cross, the United States Public Buildings Administration, the Department of State, and the Department of the Interior provided the use of their auditoria for the Forty-First Annual Meeting of the American Geophysical Union, therefore be it

Resolved, That the American Geophysical Union express its great appreciation of this cooperation and request the Executive Officer of the National Academy of Sciences to express the thanks of the Union to the appropriate officials.

(4) Resolution of Thanks for the Use of Facilities for the Forty-First Annual Meeting

Whereas, The National Academy of Sciences has provided the use of meeting rooms and other services for the Forty-First Annual Meeting of the American Geophysical Union, therefore be it

Resolved, That the American Geophysical Union express its great appreciation of this cooperation, extended over many years, and instruct the Gen-

eral Secretary to express the thanks of the Union to the appropriate official.

Resolutions (5), (6), (7), and (8) were proposed in the Section of Geodesy and recommended to the General Assembly for passage.

(5) RESOLUTION REGARDING THE CONTINUING WORK OF THE INTERNATIONAL LATITUDE SERVICE

WHEREAS, The future of the International Latitude Service (ILS) is now under consideration by the International Union of Geodesy and Geophysics, and

WHEREAS, Recent analysis of the results of the ILS indicate the probable existence of secular and long-period motions of the pole for the interval 1900–1960, which should be further studied, and

WHEREAS, It is of the utmost importance that the continuity of the ILS observations shall not be broken, be it

RESOLVED, That the International Latitude Stations shall continue to make observations at the present sites, and with present equipment, and that the computation of the coordinates of the pole by the Central Latitude Bureau of the ILS and the publication of the results shall be similar in principle to that previously employed, in particular, as given in Volume 9 of the *Results of the ILS*.

(6) RESOLUTION REGARDING THE RESULTS OF THE INTERNATIONAL LATITUDE SERVICE

WHEREAS, The results of the ILS are needed promptly for the determination of latitude, longitude, and time, as well as for geophysical studies, and

WHEREAS, The use of electronic calculators will enable the preliminary and final results of the ILS to be issued with greater speed than was previously possible, be it

RESOLVED, That increased financial support should be given to the Central Latitude Bureau by the appropriate agency to enable the use of electronic calculators in reducing the observations.

(7) RESOLUTION REGARDING THE MOTION OF THE POLE

WHEREAS, The total motion of the pole can also be determined by chains of stations which utilize modern instruments of several types, and that these chains might replace the ILS chain in the future, and

WHEREAS, No complete chain has ever existed in the southern hemisphere, be it

RESOLVED, That new, complete chains of stations, which use modern types of instruments shall be established, especially in the southern hemisphere. Be it further

RESOLVED, That copies of these resolutions shall be forwarded to cognizant officials of the International Association of Geodesy and Geophysics and of the International Astronomical Union.

(8) RESOLUTION ON THE GEODETIC SATELLITE

WHEREAS, The artificial Earth satellite offers the best means of determining the precise figure of the Earth, of correlating the world's geodetic datums, and of evaluating the Earth's gravitational field, and

WHEREAS, The science of rocketry has reached such a stage as to be reasonably sure of success in placing such a satellite in orbit, therefore be it

RESOLVED, That the American Geophysical Union urge the National Aeronautics and Space Administration to proceed promptly with its plans to develop a high-altitude satellite that may be tracked both optically and electronically, to take the lead in coordinating, among the various federal agencies, an observing program during the useful period of the satellite, and to launch the satellite into orbit as soon as possible after the observing equipment has been procured and an orderly observing program arranged.

In addition another resolution presented by H. W. Straley, III, urging that hereafter the meetings of AGU should be arranged so that there will be no conflict with other Earth-science organizations, was referred to the Executive Committee for further consideration.

UNFINISHED BUSINESS

H. H. Howe asked for a statement regarding what had been done with regard to the metric system in the United States. President Berkner replied that Chairman Floyd W. Hough of our Special Committee for the Study of the Metric System in the United States has reported regularly to the Executive Committee and that his reports will be found in the minutes of Executive Committee meetings. Two bills are before Congress at this time and there is a great deal of pressure for serious consideration of these bills.

NEW BUSINESS

H. H. Howe noted that as many as seven sessions occurred simultaneously at our Annual Meeting and suggested that an effort should be made so that there will at least be no conflict of other sessions when a General Assembly of the Union is being held. President Berkner noted that there has been a proposal by a group on the West Coast to organize National West Coast Annual Meetings which should reduce the pressure at the time of the Annual Meeting.

Adjournment—The Business Meeting adjourned at 16h 23m.

A. NELSON SAYRE, *General Secretary*
WALDO E. SMITH, *Executive Secretary*

Evening Session

Preceeding the Evening Session on April 29, there was a subscription dinner at the Willard Hotel in honor of Francis Birch, the Twenty-Second Bowie Medal Recipient. This was attended by 100 persons.

The Evening Session was called to order by

President Lloyd V. Berkner at 20h 30m in the Lecture Room of the National Academy of Sciences. About 200 were in attendance.

After appropriate remarks, President Berkner called on Perry Byerly who, on behalf of the William Bowie Medal Committee, cited Francis Birch of Harvard University as the Twenty-Second Recipient of the Medal in accordance with the remarks set forth earlier in this issue. President Berkner then made the presentation and the Recipient indicated acceptance in his response likewise set forth earlier in this issue.

Following this presentation President Berkner introduced Anton L. Hales of the Bernard Price Institute of Geophysical Research of the University of Witwatersrand, Johannesburg, South Africa, now engaged in research in the Department of Terrestrial Magnetism of the Carnegie Institution of Washington, who presented a very interesting paper entitled *Seismic and Gravity Research on Crustal Structure in South Africa*. It is anticipated that this will be published in due course in the *Journal of Geophysical Research*.

At the close of this address a social hour with refreshments was held in the Great Hall of the National Academy of Sciences.

APPENDIX A—Minutes of the Annual Meeting of 1960, Planning Committee on Planetary Sciences

Scientific sessions were held as follows.

Wednesday, April 27, 1960, 09h 00m, Auditorium

General Services Building

Theoretical Physics (G. J. F. MacDonald, Chairman)

(1) THOMAS KELSALL: Størmer Theory and the Behavior of Solar Protons in the Geomagnetic Field
(2) STANLEY C. FREDEN AND R. STEPHEN WHITE: Spectrum of Trapped Particles in the Inner Radiation Belt
(3) W. N. HESS: The Radiation Belt Produced by Neutrons Leaking Out of the Atmosphere of the Earth
(4) F. HOYLE AND T. GOLD: Origin of Solar Flares
(5) E. H. VESTINE AND W. L. SIBLEY: The Geomagnetic Field in Space, Ring Currents, and Auroral Isochasms
(6) S. OLBERT: Transfer of Angular Momentum from an Electromagnetic Wave to a Plasma in a Magnetic Field
(7) P. MUSEN, A. BAILIE, AND R. BRYANT: The Influence of Solar Radiation Pressure on the Perigee Height of Vanguard I
(8) FRANCIS S. JOHNSON: The Gross Character of the Geomagnetic Field in the Solar Wind
(9) YOSHIHIDE KOZAI: The Gravitational Field of the Earth Derived from Satellites 1958 Beta Two and 1959 Iota One

Thursday, April 28, 1960, 14h 00m, Great Hall National Academy of Sciences

Cosmic Rays (Scott Forbush, Chairman)

(10) J. A. LOCKWOOD AND J. H. TRAINOR: On the Long-Term Variation in the Cosmic Radiation
(11) R. R. BROWN AND R. G. D'ARCY: Observations of Solar Cosmic Rays near the Auroral Zone
(12) SERGE A. KORFF AND ROBERT C. HAYMES: Radiation Observed at Balloon Levels with Cosmic-Ray Counters during an Auroral Display
(13) O. A. SCHAEFFER, R. W. STOENNER, AND R. DAVIS, JR.: Argon 37 and Argon 39 from the Hamlet Fall of October 1959, and Its Relation to the Spatial Constancy of Cosmic Rays
(14) IRVINE PAGHIS: A Study of Geomagnetic Disturbances during the Recent Solar Cycle
(15) F. T. HADDOCK AND M. R. KUNDU: Solar Radio Emission and Solar Cosmic Rays
(16) J. A. LOCKWOOD AND J. H. TRAINOR: Decrease of Cosmic-Ray Intensity February 11, 1958
(17) H. CARMICHAEL AND J. S. STELJES: Evidence at Ground Level for Solar Injection on July 17, 1959

Friday, April 29, 1960, 09h 00m, Great Hall National Academy of Sciences

Meteorites (H. C. Urey, Chairman)

(18) DAVID E. FISHER: Comparative Ages of Stone and Iron Meteorites
(19) EDWARD ANDERS: Thallium 205 and the Age of the Solar System
(20) O. A. SCHAEFFER AND R. DAVIS, JR.: The Measurement of the Argon 39 Contents of Three Chondrites
(21) E. L. FIREMAN AND J. DEFELICE: Argon Radioactivity in a Recently Fallen Meteorite—A Deep-Space Probe for Cosmic Rays
(22) J. ROSINSKI AND R. SNOW: Secondary Particulate Matter in a Meteoric Trail
(23) GUSTAV A. KISTNER AND F. BEHN RIGGS, JR.: Electron-Probe X-ray Microanalysis of Micrometeorites
(24) W. A. CASSIDY AND L. F. HERZONG: Rb/Sr and K/Ca in Tektites by X-ray Fluorescence
(25) JAMES R. ARNOLD: Cosmic-Ray Induced Radioactivity in Meteorites
(26) EDWARD ANDERS, ROLAND HEYDEGGER, JAMES

KEITH, GEORGE W. REED, AND ANTHONY TURKEVICH: Cosmic-Ray Induced Radioactivity in a Fresh Meteorite

(27) P. B. GALLAGHER: 'Sporadic Showers' of Meteors

(28) RICHARD E. MCCROSKY: A Proposal for the Observation of Meteorites in Flight and Their Recovery

(29) PETER SIGNER AND ALFRED O. NIER: A Model for the Production of Rare Gases in Iron Meteorites by Cosmic-Ray Bombardment

Friday, April 29, 1960, 14h 00m, Auditorium Department of the Interior

Energetic Particles and Magnetic Fields
(Homer E. Newell, Chairman)

(30) J. A. SIMPSON, C. Y. FAN, AND P. MEYER: Preliminary Results from the Space Probe *Pioneer V*

(31) R. L. ARNOLDY, R. A. HOFFMAN, AND J. R. WINCKLER: Radiation Measurements made by Space Probe *Pioneer V*

(32) P. J. COLEMAN, D. L. JUDGE, E. J. SMITH, AND C. P. SONETT: Measurements of the Geomagnetic and Interplanetary Magnetic Fields: *Pioneer V*

(33) C. E. MCILWAIN AND P. ROTHWELL: Spatial Dependence of the Intensity of Charged Particles Trapped in the Earth's Field between 50° N and 50° S Geographic Latitude and 300-2000 Km Altitude

(34) E. J. SMITH, P. J. COLEMAN, D. L. JUDGE, AND C. P. SONETT: Characteristics of the Extraterrestrial Current System: *Explorer VI*

(35) J. C. CAIN, J. D. STOLARIK, I. R. SHAPIRO, AND J. P. HEPPNER: Report on the Analysis of Magnetic Field Data from Satellite 1959 Eta

Instrumentation for Space Physics

(36) ALFRED O. NIER: Magnetic Deflection Mass Spectrometers for Upper Atmosphere or Space Investigations

(37) R. L. LEADABRAND AND R. B. DYCE: New Instrumentation for Radar Astronomy Research at Stanford University and Stanford Research Institute

(38) H. BRIDGE, C. GILWORTH, E. LYON, R. ROSSI, AND F. SCHERB: An Instrument for the Investigation of Interplanetary Plasma

(39) W. KRAUSHAAR AND G. CLARK: Experiments in Gamma-Ray Astronomy

(40) RICCARDO GIACCONI: Soft X-ray Astronomy

(41) JOHN BENSKO: Scientific and Reconnaissance Vehicles for the Lunar Environment

Saturday, April 30, 1960, 09h 00m, Great Hall National Academy of Sciences

Planetary Atmospheres
(J. W. Chamberlain, Chairman)

(42) S. F. SINGER: Radiation Belts of the Planet Mars

(43) GEORGE B. FIELD: A Model for the Decimeter Radiation by Jupiter

(44) E. J. OPIK: The Atmosphere and Haze of Mars

(45) YALE MINTZ: Temperature and Circulation of the Venus Atmosphere

(46) V. C. PINEO, L. G. KRAFT, AND H. W. BRISCOE: Incoherent Backscatter from the Ionosphere Observed at 440 Mcps

(47) ROBERT A. HELLIWELL AND LINDEN H. MARTIN: Very Low Frequency Observations in the Antarctic

(48) ROBERT FLEISCHER AND RAYMOND E. FALCONER: Some Effects of Tropospheric Disturbances on the Reception of 18 Megacycle Cosmic Noise Signals

(49) F. R. ZABRISKIE: The Hydrogen Content of Jupiter's Atmosphere

Saturday, April 30, 1960, 14h 00m, Reading Room National Academy of Sciences

Planetary Atmospheres
(J. W. Townsend, Chairman)

(50) JAMES W. WARWICK AND ROBERT H. LEE: Observations of the Spectrum of Jupiter's Decametric Radio Emission, January and February 1960

(51) VON R. ESHLEMAN: Radar Studies of the Cislunar Medium

(52) R. C. BARTHLE: Radar Echoes from the Sun

(53) T. HAGFORS: The Effect of Lunar Surface Roughness on the Determination of Cislunar Electron Density by Continuous-Wave Methods

(54) P. WARNECK, J. O. SULLIVAN, AND F. F. MARMO: Photochemical Processes in the Atmosphere of Mars

(55) H. KORF KALLMANN: Variable Atmospheric Properties Derived from High-Altitude Observations

(56) E. MANRING, J. BEDINGER, H. B. KNAFLICH, AND R. LYNCH: Measurements of Upper Atmospheric Winds and Diffusion Coefficients

(57) RITA C. SAGALYN AND MICHAEL SMIDDY: Rocket Measurements of Positive-Ion Densities to 512 Km

(58) S. CHANDRA, J. J. GIBBONS, AND A. K. SAHA: 300Kc/s Sounding of Nighttime E Layer and Origin of Echo Patterns

(59) D. C. HUNT AND T. E. VAN ZANDT: The Height and Time Variations of the Temperature in the F Region

(60) P. A. GOLDBERG: Global Scale Correlations of Geophysical Parameters with Extra-Low-Frequency Noise

Saturday, April 30, 1960, 09h 00m, Great Hall, National Academy of Sciences

Lunar Physics (E. H. Vestine, Chairman)

(61) G. H. PETTENGILL, J. C. HENRY, AND L. G. KRAFT: Recent Measurements of Lunar Reflectivity at 440 Mcps

(62) R. L. LEADABRAND, R. B. DYCE, A. FREDRIKSEN, R. I. PRESNELL, AND J. C. SCHLOBOHM: Evidence that the Moon Is a Rough Scatterer at Radio Frequencies
(63) FRANK PRESS, PHYLLIS BUWALDA, AND MARCIA NEUGEBAUER: Feasibility of a Lunar Seismic Experiment
(64) HAROLD C. UREY: The Duration of the Intense Bombardment of the Moon
(65) P. D. LOWMAN: A Comparison of Chemical Compositions of Tektites and Certain Sedimentary and Igneous Rocks
(66) ARNOLD C. MASON, MAXIM M. ELIAS, ROBERT J. HACKMAN, AND ANNABEL R. OLSON: Terrain Study and Map of the Surface of the Moon
(67) G. P. KUIPER, D. W. G. ARTHUR, AND E. A. WHITAKER: Lunar Exploration

ROBERT JASTROW, *Secretary*

APPENDIX B—Minutes of the Annual Meeting of 1960, Section of Geodesy

The Forty First Annual Meeting of the Section of Geodesy was called to order by President Charles Pierce at 09h 15m on April 28, 1960, in the Reading Room, National Academy of Sciences. The officers of the Section for the current triennium were introduced.

Floyd W. Hough, Vice President of the Section, gave a brief progress report on the adoption of the metric system in the United States.

Frank L. Culley, Chairman of the Resolutions Committee, submitted four resolutions which were recommended by the Section. These resolutions were submitted to the Union for adoption.

The scientific session proceeded with the following papers:

(1) ALEXANDER CORPACIU: Rigorous Adjustment of Flare Triangulation with Photographic Observations
(2) FREDERICK F. CEELY, JR.: Simultaneous Adjustment of Angular and Distance Measurements
(3) SOREN W. HENRIKSEN: SECOR—An instrument for Measuring Very Long Distances
(4) WILLIAM M. KAULA: Incorporation of Satellite Observations in the World Geodetic System
(5) CHARLES A. WHITTEN: Horizontal Movement in the Earth's Crust
(6) W. A. HEISKANEN: Latest Achievements of Physical Geodesy

The session recessed at 12h 10m and reassembled at 14h 00m in the Auditorium of the Department of the Interior, with President Pierce presiding. The following papers were presented:

(7) WILLIAM MARKOWITZ: The Secular Motion of the Pole
(8) BRUCE C. MURRAY AND NANNIELOU H. DIETER: Tangential Velocity Measurements—An Independent Approach to Geodesy
(9) R. A. HIRVONEN: Reformation of Geodesy
(10) G. P. WOOLLARD: The Relation between Isostatic Gravity Anomalies and Crustal Structure and Composition in the United States
(11) J. C. ROSE, O. STRICKHOLM, AND G. P. WOOLLARD: An East Coast Calibration Line with the Gulf-Wisconsin Quartz Pendulums
(12) R. A. HAUBRICH: Harmonic Analyses of Earth Tides as Measured from Gravity Variations and Well-Level Fluctuations

The meeting adjourned at 16h 36m.

BUFORD K. MEADE, *Secretary*

APPENDIX C—Minutes of the Annual Meeting of 1960, Section of Seismology

President Murphy called the meeting to order at 09h 00m on April 29, 1960 in the Auditorium of the General Services Building. The minutes of the Fortieth Annual Meeting were approved as published in the *Transactions* (v. 40, pp. 142–143, June 1959). President Murphy reported on plans for the Helsinki meeting and announced changes in the scheduling of papers in other sections of possible interest to the members and the times of business and director's meetings. The following scientific papers were presented (speaker is marked with an asterisk in the case of joint papers):

(1) GERALD R. MACCARTHY: The Formation of Joints as a Possible Cause of Certain Seismic Phenomena
(2) LEON KNOPOFF: Earth Tides as a Triggering Mechanism for Earthquakes
(3) J. BRUNE*, J. NAFE, AND J. OLIVER: Radiation Pattern of Rayleigh Waves from the S.E. Alaska Earthquake of July 10, 1958
(4) WILLIAM STAUDER: A Use of S Waves in Focal Mechanism Studies
(5) WILLIAM STAUDER AND W. M. ADAMS*: A Comparison of Some S Waves Studies of Earthquake Mechanisms
(6) M. A. CHINNERY: Deformation of the Earth's Crust Around Surface Faults
(7) WILLIAM L. DONN* AND W. L. MCGUINNESS: Microseisms and Ocean Waves
(8) T. HATHERTON: Microseisms Behind an Antarctic Ice-Sheet
(9) B. LUSKIN* AND J. I. EWING: Ocean-Bottom Seismographs

The first session ended at 12h 35m.

President Murphy called the second session to order at 09h 00m on April 30, 1960 in the Reading Room of the National Academy of Sciences. The following papers were presented:

(10) M. V. BROWN, JOHN NORTHROP*, AND MAURICE BLAIK: Seismic Evidence for Post-Cretaceous Faulting Offshore, Long Island, New York

(11) GEORGE H. SUTTON, MANIK TALWANI*, AND J. LAMAR WORZEL: West-East Crustal Section Through Gravity Anomaly Belt of Lesser Antilles Along 14° 20' N

(12) GEORGE H. SUTTON* AND ROBERT W. METZGER: Observations of Earth Strain at Ogdensberg, N. J.

(13) FRANK PRESS: Observations of the Free Vibrations of the Earth

(14) PETER CHRZANOWSKI AND RICHARD K. COOK*: Radiation of Sound by Earthquake Waves

(15) JAMES DORMAN: Particle Amplitude Profiles for Rayleigh Waves in a Heterogeneous Earth

(16) Y. SATO, M. LANDISMAN*, AND M. EWING: Dispersion of Love Waves in a Heterogeneous Spherical Earth

(17) ROBERT A. PHINNEY: Leaking Modes in the Crustal Wave Guide: The Oceanic P_L Wave

(18) R. P. MEYER*, J. S. STEINHART, G. P. WOOLLARD, AND W. E. BONINI: Refraction Phase Correlation Techniques as Applied to and Preliminary Results of Crustal Studies in Eastern Montana

(19) J. S. STEINHART*, R. P. MEYER, AND G. P. WOOLLARD: Statistical Uncertainty and Interpretation Problems in Seismic Crustal Studies with Applications

The Annual Meeting adjourned at 13h 20m.

B. F. HOWELL, JR., *Secretary*

APPENDIX D—Minutes of the Annual Meeting of 1960, Section of Meteorology

The Business Session of the Section of Meteorology was called to order by President Thomas F. Malone at 09h 00m, Thursday, April 28, 1960. The minutes of the Fortieth Annual Meeting were approved as published in the *Transactions* (v. 40, pp. 143–145, June 1959). A Resolutions Committee, composed of Jerome Namias, Chairman, and Conrad Mook was appointed to serve during the course of the meetings.

The President outlined plans for the IUGG meetings scheduled for Helsinki, Finland, in July and read a report prepared by Horace Byers, Chairman of the Section's Committee on International Participation. The report outlined the proposed agenda and activities of the International Association of Meteorology and Atmospheric Physics. The President also reported upon the activities of the Section in its endeavor to obtain closer ties with the other sections of the American Geophysical Union.

Conrad Mook briefly discussed publication policies of the *Journal of Geophysical Research*.

The meeting was adjourned at 09h 15m and was followed immediately by the third of the series of scientific sessions which were held jointly with the American Meteorological Society. The program is published below.

Wednesday, April 27, 1960, 09h, 00m, Auditorium, D. C. Chapter, American Red Cross

Wind Systems (Hans A. Panofsky, Chairman)

(1) J. K. ANGELL: An Analysis of High-Frequency Fluctuations in Transosonde-Derived Wind Velocities

(2) LAWRENCE B. SMITH: Monthly Observations of Winds between 150,000 and 300,000 Feet over a One-Year Period

(3) H. T. MANTIS: The Lagrangian Spectrum of Upper Atmospheric Motions over a Large Frequency Range

(4) JOSEPH B. KNOX: An Investigation of the Divergent Wind Field

(5) CHESTER W. NEWTON: Synoptic Structures of Jet-Stream and Gulf-Stream Fronts

(6) DONALD H. PACK AND J. K. ANGELL: An Analysis of Low-Level Constant Level Balloon (Tetroon) Flights

(7) FRANK E. MCCREARY, JR., WILLIAM W. ELAM, AND DONALD R. JONES: Seasonal Variation of the Upper Tropospheric Flow over the Tropical Pacific during 1958

(8) MURRAY J. YOUNG AND THOMAS D. POTTER: Comparison of Methods to Determine the Probable Impact Areas in the Planning of Short-Range Instrumented Balloon Flights

(9) C. EUGENE BUELL: The Synoptic Scale Structure of Wind Correlations in the Atmosphere

(10) ABRAHAM ARNOLD AND RAYMOND BELLUCCI: The Variability of Upper Winds

Wednesday, April 27, 1960, 14h 00m, Auditorium, D. C. Chapter, American Red Cross

Micrometeorology and Instrumentation (Lester Machta, Chairman)

(11) DUANE A. HAUGEN: A Study of a Lagrangian-Eulerian Relationship for Turbulent Diffusion in the Atmospheric Boundary Layer

(12) HANS A. PANOFSKY, A. K. BLACKADAR, AND G. E. MCVEHIL: The Diabatic Wind Profile

(13) MARIANO A. ESTOQUE AND DONALD W. STEVENS: A Numerical Model for Micrometeorological Research

(14) WILLIAM G. TANK: Optical Techniques for Studying Microscale Turbulence
(15) FLOYD C. ELDER, DONALD J. PORTMAN, EDWARD RYZNAR, AND FRANK R. BELLAIRE: Some Results of an Investigation of Light-Intensity Scintillation in the Surface Layer of the Atmosphere
(16) WILLIAM C. BARR: Theoretical Evaluation of Cylindrical Chaff as a Wind Sensor at High Altitude
(17) ROBERT M. NELSON: Improved Neoprene Sounding Balloons and New Applications
(18) WALTER C. CONOVER: Radiosonde Modulator Using a Hypsometer
(19) B. R. BEAN AND E. J. DUTTON: On the Calculation of Non-Standard Bending of Radio Waves
(20) R. E. BAILEY, W. CANNON, A. CASSANO, M. POLAN, S. SMILOWITZ, AND A. RICHTER: A Proposed Computer for Fallout Prediction

Thursday, April 28, 1960, 09h 15m, Auditorium
D. C. Chapter, American Red Cross

General Session (Jerome Namias, Chairman)
(21) JAY S. WINSTON AND ARTHUR F. KRUEGER: Some Aspects of a Cycle of Available Potential Energy
(22) D. O. STALEY: An Evaluation of Potential Vorticity Changes in the Vicinity of the Tropopause
(23) DONALD L. GILMAN: A Test of the Forecaster's Skill at Specifying Weather from Circulation
(24) ALFRED K. BLACKADAR AND MELVIN H. RAJALA: Hydrostatic Stability as a Factor in the Propagation of Pressure Systems
(25) RICHARD A. CRAIG: Dynamic Analysis of a Stratospheric Warming
(26) NORMAN J. MACDONALD AND ROBERT W. KNECHT: A Possible Effect of Lower Atmospheric Divergence on the Local Electron Density in the Ionosphere (presented by James Warwick)
(27) J. VERNE HALES, THOMAS L. WILLIAMS, AND DONALD HENDERSON: Estimates of Long-Wave Terrestrial Radiation Flux at Very High Elevations

Thursday, April 28, 1960, 14h 00m, Auditorium
D. C. Chapter, American Red Cross

Numerical-Statistical Forecasting
(George P. Cressman, Chairman)
(28) JOHN A. BROWN, JR., AND JAMES R. NEILON: Case Studies of Numerical Wind Analyses
(29) A. WIIN-NIELSEN: On the Relative Distribution of Temperature and Pressure in Planetary Stationary Waves
(30) FREDERICK G. SHUMAN: The Numerical Integration of a Two-Layer Model
(31) JOSEPH VEDERMAN: Precipitation Forecasts with the Aid of a High-Speed Computer
(32) HAROLD A. BEDIENT: The New Input-Output System of JNWP
(33) BENJAMIN W. HELMICK: Forecasting Temperature Changes by Numerical Methods
(34) KEITH W. VEIGAS: Prediction Models in a Moving Coordinate System
(35) FREDERICK P. OSTBY AND KEITH W. VEIGAS: East Coast Cyclones—A Moving Coordinate Model Prediction Experiment
(36) DUANE S. COOLEY: Statistical Prediction of 500-mb Wind

Thursday, April 28, 1960, 14h 00m, Auditorium
Department of State

Climatology and Physical Meteorology
(Helmut E. Landsberg, Chairman)
(37) ADAM KOCHANSKI: Estimating 20th, 10th, and 5th Percentile of Air Density at Ground-Level
(38) NICHOLAS E. MANOS: Statistical Bioclimatology
(39) ROLF M. NILSESTUEN: Correlation between Integrated Wind and Integrated Density
(40) C. P. WOOD, W. C. SPREEN, AND M. J. YOUNG: Comparison of Temperature and Density Correlations
(41) ROLAND J. BOUCHER AND RAYMOND WEXLER: The Motion and Predictability of Precipitation Lines
(42) GLENN W. BRIER: A Test of the Reality of Rainfall Singularities
(43) DWIGHT B. KLINE: On the Measurement of Ice Nuclei Concentrations in the Free Atmosphere
(44) ROBERT W. FENN: Measurements of the Concentration and Size Distribution of Particulates in the Arctic Air of Greenland
(45) MARVIN N. HUNTER: A Theory Concerning the Geomagnetic-Solar Influence on Weather and Climate

Thursday, April 28, 1960, 17h 00m, Great Hall
National Academy of Sciences

TIROS Status Report (Morris Tepper, Chairman)
(46) JULES LEHMAN: Payload and Ground Equipment
(47) HERBERT BUTLER AND DUDLEY CLINE: Testing, Calibration, and Data Acquisition
(48) W. G. STROUD (Goddard Space Flight Center): TIROS Operations
(49) SIGMUND FRITZ: Some Meteorological Phenomena Revealed by TIROS
(50) JOHN CONOVER: Identification of Cloud Forms
(51) RADIO CORPORATION OF AMERICA, Film: This is TIROS

Friday, April 29, 1960, 09h 00m, Auditorium
Department of State

Meteorological Rockets and Satellites
(Morris Tepper, Chairman)

(52) H. J. AUFM KAMPE: The Meteorological Rocket Network
(53) H. W. COOPER, I. S. GULLEDGE, M. J. KOOMEN, AND D. M. PACKER: Altitude Distribution of Night Airglow Emissions by Rocket-Borne Photometers
(54) JOHN STRONG, M. D. ROSS, AND C. B. MOORE: Some Observations of the Atmospheres of Venus and the Earth during the Strato Lab IV Balloon Flight
(55) LESTER F. HUBERT: Utilization of High Altitude Cloud Photography
(56) ROBERT C. CURTIS: The Large-Scale Cloudiness of the Northern Hemisphere
(57) JOHN H. CONOVER: Cloud Patterns as Seen from High Altitude, and Related Air Motions
(58) RAYMOND WEXLER AND LEWIS D. KAPLAN: On Satellite Observation of Infrared Radiation
(59) DAVID Q. WARK: The Calculation of Outgoing Radiation from the Atmosphere
(60) VERNER E. SUOMI: Some Meteorological Data Obtained from the Explorer VII Satellite

Friday, April 29, 1960, 14h, 00m, Reading Room
National Academy of Sciences

Severe Storms (Thomas F. Malone, Chairman)
(61) HARRY F. HAWKINS: Vertical Wind Profiles in Hurricanes
(62) NOEL LASEUR: Physical Aspects of Hurricane Cleo
(63) R. C. GENTRY: Research-Data Availability of the National Hurricane Research Project (presented by Harry F. Hawkins)
(64) LLOYD W. VANDERMAN: Verification of JNWP Unit Hurricane and Typhoon Forecasts for 1959
(65) WALTER H. HOECKER, JR.: Characteristics Common to Several Tornado Systems
(66) GEORGE T. DELLERT, JR.: Data Processing Procedures in Numerical Mesoanalysis
(67) L. F. CONOVER: Weather Detection Capabilities of the WSR-57 Radar
(68) T. FUJITA: Animation of Hourly Precipitation Analyses

Friday, April 29, 1960, 14h 00m, Auditorium
Department of State

Oceanography—Meteorology (Robert O. Reid, Chairman), Meeting jointly with Section on Oceanography
Symposium on Wind Stress
(arranged by Dale F. Leipper, Chairman)
(69) GERHARD NEUMANN: On Micro-Meteorological Observations in the Air-Sea Boundary Layer with Special Reference to the Wind-Stress (presented by W. J. Pierson)
(70) JAMES W. DEARDORFF: Conditions which May Affect the Wind-Stress on Natural Waters
(71) JOSEPH PANDOLFO: Turbulent Wind Measurements over the Sea Surface
(72) WILLIAM G. VAN DORN: Wind Stress Measurements over an Enclosed Atoll
(73) DONALD J. PORTMAN AND JOHN C. AYERS: An Improved Technique for Measuring Wind- and Temperature-Profiles over Water and Some Results Obtained for Light Winds
(74) OWEN PHILLIPS AND WALTER MUNK: Papers to be discussed by Owen Phillips, and summarized by Walter Munk
Local Heat Flux Studies
(75) JAMES D. KANGOS: A Preliminary Investigation of the Heat Flux from the Ocean to the Atmosphere in Antarctic Regions
(76) JOSE A. COLON: Seasonal Variations in the Heat Flux from Ocean to Atmosphere over the Caribbean Sea

Saturday, April 30, 1960, 09h 00m, Lecture Room
National Academy of Sciences

Symposium on Sferics and Thunderstorm Electricity—Part I (Bernard Vonnegut, Chairman) Sponsored jointly with Commission IV, U. S. National Committee, International Scientific Radio Union (URSI)
(77) E. A. LEWIS, R. B. HARVEY, AND J. E. RASMUSSEN: Hyperbolic Direction Finding with Sferics of Trans-Atlantic Origin
(78) J. DOYNE SARTOR: Some Electrostatic Cloud-Droplet Collision Efficiencies
(79) H. L. JONES, F. J. BOUDREAUX, AND W. D. WOODRUFF: Quasi-Static Electric Field Studies of Thunderstorms
(80) E. T. PIERCE: Atmospherics from Lightning Flashes with Multiple Strokes
(81) M. BROOK AND N. KITAGAWA: Electric-Field Changes and the Design of Lightning-Stroke Counters
(82) W. L. TAYLOR: Daytime Attenuation Rates in the VLF Band Using Atmospherics (presented by Charles J. Chilton)

Saturday, April 30, 1960, 14h 00m, Lecture Room
National Academy of Sciences

Symposium on Sferics and Thunderstorm Electricity—Part II (William Q. Crichlow, Chairman) Sponsored jointly with Commission IV, U. S. National Committee, International Scientific Radio Union (URSI)
(83) HEINZ W. KASEMIR: A Contribution to the Electrodynamic Theory of the Main Stroke of a Lightning Discharge
(84) B. VONNEGUT, C. B. MOORE, AND BARRY STEIN: Observations of Electrification and Lightning in Warm Clouds
(85) E. L. HILL: Ball Lightning as a Physical Phenomenon
(86) N. KITAGAWA, M. BROOK, AND E. J. WORKMAN: The Role of Continuous Discharges in Cloud-to-Ground Lightning
(87) M. M. NEWMAN: Thunderstorm Electrical

Discharges Intercepted by Aircraft and Related Ball Lightning and Sferics Phenomena (presented by John Robb)

(88) B. VONNEGUT AND C. B. MOORE: Airplane Instrumentation for the Measurement of Atmospheric Potential Gradient and Space Charge

W. C. JACOBS, *Secretary*

APPENDIX E—Minutes of the Annual Meeting of 1960, Section of Geomagnetism and Aeronomy

The Forty-First Annual Meeting of the Section of Geomagnetism and Aeronomy was called to order by President L. R. Alldredge at 09h 00m, Thursday, April 28, 1960, in the Lecture Room, National Academy of Sciences. The speaker is marked by an asterisk. The first session (Thursday morning) was devoted to the presentation of the following papers:

(1) M. G. ROCHESTER: Earth's Timekeeping and Its Magnetic Field

(2) JAMES T. ARNOLD, WILLIAM E. BELL*, ARNOLD L. BLOOM, AND LYNN R. SARLES: A Rubidium Vapor Magnetometer and Its Performance in the Geomagnetic Field

(3) T. CANTWELL* AND T. R. MADDEN: Detection and Analysis of the Magnetotelluric Field

(4) V. P. HESSLER: Earth Current Activity on Drifting Station Charlie

(5) R. HUTCHINSON* AND B. SHUMAN: Rocket Measurements of the Magnetic Field Above HMDC, New Mexico

(6) PETER CHRZANOWSKI, GARY GREENE, K. T. LEMMON, AND J. M. YOUNG*: Traveling Pressure Waves Associated with Geomagnetic Activity

(7) ALVIN W. JENKINS JR.,* CHARLES A. PHILLIPS JR., AND ELWOOD MAPLE: Observed Correlation Between Geomagnetic Fluctuations and Meteor Rates

(8) DAVID W. STRANGWAY: Magnetic Studies of Some Diabase Dikes

(9) ALLAN COX: Variations in the Direction of the Dipole Component of the Earth's Magnetic Field

(10) MARVIN H. WILKENING* AND JOHN E. HAND: Radon Flux At the Earth-Air Interface

A short business meeting constituted the first part of the second session (Thursday afternoon), beginning at 14h 00m in the Lecture Room. President Alldredge announced the decision of the editors of the *Journal of Geophysical Research* to continue indefinitely the publication of Solar and Geomagnetic Data in the *Journal*. Thanks of the Section of Geomagnetism and Aeronomy are due to the Boulder Laboratories of the National Bureau of Standards, specifically to Miss J. Virginia Lincoln, for editing and preparing the copy for publication.

President Alldredge gave a brief status report on the Planning Committee on Planetary Sciences, announced the composition of the Section Committees, and reported very briefly on the formation and objectives of the International Geophysical Committee (CIG). He also described the rumored proposals for the establishment of Permanent Services for (a) World Magnetic Surveys, (b) Rapid Magnetic Variation Data, and (c) Aurora and Air Glow Reporting.

After the business session the following papers were presented:

(11) WULFGANG BERTHOLD, ARTHUR HARRIS*, AND HAROLD J. HOPE: World-Wide Effects of Hydromagnetic Waves Due to Argus

(12) A. J. DESSLER* AND R. KARPLUS: The Gap in the Electron Component of the Outer Zone of the Van Allen Radiation Belt

(13) E. H. VESTINE: Geomagnetic Control of the Van Allen Radiation Belts

(14) ALFRED J. ZMUDA: The Mutual Dependence of Harmonic Coefficients.

(15) M. H. DAVIS: The Electrostatic Problem of Two Spheres in a Uniform Field

(16) PAUL F. FOUGERE*, JOHN F. MCCLAY, AND ABRAHAM L. EPSTEIN: Spherical Harmonic Analysis of Magnetic Observatory Data

(17) DUANE C. JENSEN: A Spherical Harmonic Analysis of the Geomagnetic Field (presented by Lew Allen)

(18) JOHN H. MATHEWS* AND W. K. GARDNER: Disk-Dynamo Core Model Implying Recurrent Geomagnetic Reversal
Related to the last paper was a brief presentation by

(19) WILLIAM OVERTON: Calculation of the Electrical Conductivity and the Dynamic Rigidity of the Earth's Core

The third session (Friday morning) was called to order by Vice President C. T. Elvey at 09h 00m. The following papers were presented:

(20) ELWOOD MAPLE*, ALVIN W. JENKINS, AND CHARLES A. PHILLIPS: Sub-Audio-Frequency (1 to 50 c/s) Geomagnetic Fluctuations at Denver, Colorado

(21) GEORG GUSTAFSSON, JULES AARONS*, AND ALV EGELAND: Audio-Frequency Electromagnetic Radiation in the Auroral Zone

(22) LEE R. TEPLEY: Slow Tails From Intra-Cloud Lightning Discharges

(23) Z. F. DANES: A Note On the Aurora Polaris

(24) WALLACE B. MURCRAY: Correlation Between the Luminous Aurora and Some Other Phenomena

(25) FRANCIS S. JOHNSON: Heat Transfer from the Auroral Zone Ionosphere
(26) WALLACE H. CAMPBELL: Micropulsations in the Earth's Magnetic Field and Their Relationship to the Pulsating Aurora
(27) C. O. HINES: The Theory of Large-Scale Traveling Disturbances in the Ionospheric F Layer
(28) S. MATSUSHITA: Day-to-Day and Seasonal Changes of the Central Position of the S_q Overhead Current System

The fourth session (Friday afternoon) was called to order by A. J. Dessler as invited chairman at 14h 00m. The following papers were presented:

(29) W. E. FRANCIS*, A. J. DESSLER, AND E. N. PARKER: Geomagnetic Storm Sudden Commencement Rise Times
(30) KENNETH L. BOWLES AND ROBERT COHEN*: A Study of the Equatorial Electrojet by Radio Techniques
(31) ALFRED J. ZMUDA: Ionospheric Electrostatic Fields and the Equatorial Electrojet
(32) R. KARPLUS*, W. E. FRANCIS, AND A. J. DESSLER: Ionospheric Heating During Geomagnetic Storms
(33) W. B. HANSON* AND F. S. JOHNSON: Electron Temperatures in the Ionosphere
(34) EDWIN J. CHERNOSKY: The Time-Phased Superposed Epoch Method of Analysis and an Application to Geomagnetic Activity Studies

The fourth session adjourned at about 16h 05m. In general, a period of about five minutes was used after each paper for discussion. Many of the comments showed keen interest on the part of the listeners. Attendance at the four sessions varied from about 60 to 175, an average figure being probably 120.

J. HUGH NELSON, *Secretary*

APPENDIX F—Minutes of the Annual Meeting of 1960, Section of Oceanography

The meeting was called to order by the president Walter Munk at 09h 10m on Thursday April 28, 1960. Proceedings of the previous Executive Committee Meeting were reported to the Section.

A committee composed of John Lyman, Chairman, Dale Leipper, and Don Pritchard was appointed to review the needs of the Oceanographic Section as to publications of the AGU and other related matters.

At the request of Gerald Richmond, Chairman pro tem, of International Association on Quaternary Research (INQUA), a committee consisting of Bruce Heezen and Edwin Hamilton was appointed to represent the Oceanographic Section on INQUA matters.

The business meeting was then adjourned and the last scientific session begun. One hundred and forty members and guests registered for the oceanographic sessions.

The following papers were presented at the scientific sessions. The speaker is marked by an asterisk.

(1) WILLARD J. PIERSON, JR.: Theoretical and Observed Results on the Nonlinear Properties of Capillary Waves with Emphasis on Wavelengths near 2.44 cm
(2) ALLEN H. SCHOOLEY: Double, Triple, and Higher Order Dimples in the Profiles of Wind-Generated Water Waves in the Capillary-Gravity Transition Region
(3) BASIL W. WILSON: Deep-Water Wave Generation by Moving Fetches of Variable Wind
(4) LEDOLPH BAER: A Realistic Model Sea Surface for Engineering Design Purposes
(5) ROBERT O. REID* AND ALYN C. DUXBURY: The Transition from Poincaré-Kelvin Boundary Waves to Stokes-Type Edge Waves in a Rotating Semi-Infinite Sea
(6) BASIL W. WILSON: Note on Surface Wind Stress over Water at Low and High Wind Speeds
(7) RHODES W. FAIRBRIDGE: Long-Range Correlation of Solar Radiation, Climate, and Sea-Level Cycles
(8) CHARLES D. KEELING* AND NORRIS W. RAKESTRAW: The Concentration of Carbon Dioxide in the Atmosphere
(9) YOSHIO SUGIURA, E. R. IBERT*, AND D. W. HOOD: Mass Transfer of Carbon Dioxide across Simulated and Natural Sea Surfaces
(10) TABO TAKAHASHI*, R. GERARD, AND S. FRIEDMAN: Carbon Dioxide Exchange between the North Atlantic Ocean and the Atmosphere
(11) DALE F. LEIPPER: Oceanography and Meteorology, Ten Years at Texas A and M College
(12) G. B. AUSTIN: Notes on the Nearshore Marine Environment of the Gulf of Mexico at Panama City, Florida
(13) G. B. AUSTIN AND R. H. PAYNE*: Results Obtained from a Preliminary Investigation of Marine Discontinuity Zones in the Ocean near Panama City, Florida
(14) W. H. MUNK*, F. E. SNODGRASS, AND G. R. MILLER: Directional Spectra of Waves from the Southern Oceans
(15) W. H. TOLBERT: On the Concentration and Size Distribution Particulate Matter in Sea Water
(16) J. H. CARPENTER: An Improved Fluores-

cent Tracer Technique for Studies of Water Movement and Dispersion

(17) D. W. PRITCHARD: Some Preliminary Results of Direct Observations on Water Movement and Dispersion Using a New Fluorescent Tracer Technique

(18) MARSHALL SCHALK: A Light-Weight Bottom Sampler for Sand or Gravel

(19) EUGENE C. LAFOND: Isotherm Follower

(20) DAYTON E. CARRITT: Some Problems Associated with Oceanographic Measurements of Dissolved Oxygen

(21) M. J. POLLAK: Wind Set-Up and Shear-Stress Coefficient in Chesapeake Bay

Another scientific session sponsored jointly with the Section of Meteorology on Wind Stress and on Heat Flux Studies was held April 29 at 14h 00m and is reported in the Minutes of the Section of Meteorology.

EUGENE LAFOND, *Secretary*

APPENDIX G—Minutes of the Meeting of the Section of Volcanology, Geochemistry, and Petrology

The business meeting was called to order at 14h 00m, Thursday, April 28, 1960 by President A. O. Nier.

The President announced that the Program Committee had forwarded 16 papers to G. Laclavere to be included in the General Geochemical Sessions at Helsinki. In addition to this group of papers submitted through the section, two symposia of interest to geochemists have been organized.

J. F. Schairer, Vice President of the International Association of Volcanology, explained to the meeting the status of geochemists in the IUGG, and stated that the large representation of geochemists expected in Helsinki may make it possible to secure a permanent position in the IUGG for geochemists.

The President announced that the section had agreed to cooperate with the International Association on Quaternary Research and that we would appoint a representative to meet with INQUA. The representative will meet with a committee being organized by NAS-NRC to appoint the U. S. delegation to the next INQUA meeting in Poland in 1961. The Program Committee has agreed to sponsor a joint program with the Section of Meteorology at next year's annual meeting.

At the scientific sessions the following papers were presented.

Wednesday, April 27, 1960, 14h 00m, Auditorium General Services Building

(1) LEON T. SILVER AND SARAH DEUTSCH: An Experimental Investigation of Discordant Isotopic Ages in Zircons

(2) G. R. TILTON AND G. L. DAVIS: Solid Diffusion as a Mechanism for Discordant Lead Ages

(3) H. FECHTIG, W. GENTNER, AND J. ZÄHRINGER: Diffusion Loss of Argon in Minerals and Its Effect on the Potassium-Argon Age Measurements

(4) H. W. FAIRBAIRN, W. H. PINSON, AND P. M. HURLEY: Comparison of Rb-Sr Mineral and Whole Rock Ages at Sudbury, Ontario

(5) LEON T. SILVER, C. R. MCKINNEY, SARAH DEUTSCH, AND JAMES BOLINGER: Precambrian Age Determinations in Some Crystalline Rocks of the San Gabriel Mountains of Southern California

(6) L. T. ALDRICH AND G. L. DAVIS: Age Measurements of Rocks and Minerals in Metamorphic Regions of Northern Michigan

(7) G. P. ERICKSON AND J. L. KULP: Potassium-Argon Measurements on the Palisades Diabase and Associated Basalts

(8) EDWARD D. GOLDBERG AND MINOTU KOIDE: Ionium/Thorium Chronology of Deep-Sea Sediments

(9) HARRY J. ROSE, JR., AND THOMAS W. STERN: Spectrochemical Determination of Lead in Zircon for Lead-Alpha Age Measurements

(10) G. R. TILTON AND G. W. REED: Concentration of Lead in Ultramafic Rocks by Neutron Activation Analysis

Thursday, April 28, 1960, 09h, 00m, Auditorium General Services Building

(11) BRIAN MASON: The Origin of Chondrules and Chondritic Meteorites

(12) W. GENTNER AND J. ZÄHRINGER: The Potassium-Argon Ages of Tektites

(13) ALVIN J. COHEN AND JOHN ANANIA: Germanium and Gallium Contents of Tektites, Impact Glasses, Meteorites, and Related Materials

(14) IRVING FRIEDMAN, A. THORPE, AND FRANK SENFTLE: Tektites and Glasses from Melted Terrestrial Rocks

(15) F. T. BONNER AND O. A. SCHAEFFER: Chlorine-36 Content of Saline Great Basin Waters

(16) E. S. OLSON AND W. S. BROECKER: Bomb-Produced Radiocarbon in the Atmosphere and Biosphere

(17) W. S. BROECKER AND E. A. OLSON: Bomb-Produced Radiocarbon in the Hydrosphere

(18) HANS E. SUESS: Carbon Isotope Ratios in Pacific Ocean Water

Thursday, April 28, 1960, 14h 00m, Auditorium
General Services Building

(19) HUGH P. TAYLOR, JR., AND SAMUEL EPSTEIN: O^{18}/O^{16} Ratios in Coexisting Minerals of Igneous Rocks
(20) W. S. FYFE: Hydrothermal Synthesis and Equilibrium
(21) WILLIAM C. PHINNEY: Phase Equilibrium in the Metamorphic Rocks of St. Paul Island, Nova Scotia
(22) J. Gittins and O. F. TUTTLE: The System CaF_2-$Ca(OH)_2$-$CaCO_3$ at 1000 Bars
(23) C. WAYNE BURNHAM: A Method for Determining the Solubility of Silicates in Water Vapor at High Pressures
(24) C. WAYNE BURNHAM AND O. F. TUTTLE: The Second Critical End Point in the System $NaAlSiO_4$-H_2O
(25) SYDNEY P. CLARK, JR.: Kyanite Revisited
(26) JOHN GRIFFIN AND EDWARD D. GOLDBERG: Clay Minerals in the Pacific Ocean
(27) N. MORIMOTO AND G. KULLERUD: Crystallographic Study of the Cu_2S-Cu_2FeS_4 Join

Friday, April 29, 1960, 14h 00m, Auditorium
General Services Building

(28) JOHN VERHOOGEN: The Heat Balance of the Earth's Core
(29) A. E. BEEK: An Expanding Earth with Loss of Gravitational Potential Energy
(30) L. C. PAKISER: Gravity in Volcanic Areas, California and Idaho
(31) W. BRADLEY MYERS: Structural Deformation Accompanying the Earthquake of August 17, 1959 in Southwest Montana
(32) C. B. SLAWSON AND A. A. GIARDINI: Diamond-Bearing Kimberlite Pipes
(33) F. CHAYES: Correlation between Variables of Constant Sum
(34) HANS E. KAPP: A Comparison of the Petrography of a Tertiary Alkaline Igneous Complex in Northeastern Greenland with the Monteregian Hills of Eastern Canada
(35) J. W. WINCHESTER AND M. L. BOTTINO: Cyclotron-Charged Particle-Activation Analysis for Determining Oxygen, Carbon, and Silicon
(36) Z. F. DANES: A Chemical Correlation Factor in Gamma-Gamma Density Logging
(37) J. W. WINCHESTER AND J. H. CROCKET: Study of the Dilute Solid Solution $ZnCO_3$ in $CaCO_3$ by Radiotracer Techniques

IRVING FRIEDMAN, *Secretary*

APPENDIX H—Minutes of the Annual Meeting of 1960, Section of Hydrology

President W. B. Langbein called the Business Meeting to order at 09h 00m, April 28, 1960, in the Auditorium of the Department of State.

The President discussed the important question of publication of hydrology papers, and urged the membership to renew their efforts to obtain good papers for publication in the *Journal of Geophysical Research*. There is no space limitation, and no backlog of papers at present. The numbers of papers submitted, however, has not been encouraging. He expressed the hope that publication of several good papers would result from the technical sessions. There was objection from the floor to the page charge for publication, after which President Langbein discussed some of the financial problems of the Union.

R. N. Wilson, Secretary for International Meetings, advised that plans for the Helsinki meeting, July 25–August 6, 1960, were firm and that an excellent program in hydrology had been prepared. The total of 43 papers include 14 on ground water, 16 on glaciology, and 7 on surface water. A display of subterranean maps will be included. International symposia on (1) Forests and Waters and (2) Snow and Ice have been held since the last General Assembly in 1957. President Langbein complimented Mr. Wilson and the Committee Chairmen on the excellent manner in which preparations for the Helsinki meeting were conducted.

Vice President W. C. Ackermann, Chairman of the Committee on Awards, announced that the paper, "A General Theory of the Unit Hydrograph," by J. G. Dooge has been selected as the best hydrology paper to appear in the *Journal* during 1959 and that the Mr. Dooge will receive the Horton Award. A certificate of award will be forwarded to the author at an early date.

President Langbein indicated that the emphasis during the 1961 program will be on greater breadth and interdisciplinary aspects of hydrology, and may include a symposium.

The Business Meeting then adjourned and was followed immediately by the third scientific session (asterisk indicates the speaker). The first session convened at 09h 00m, April 27, in the Auditorium of the Department of State under the chairmanship of W. C. Ackermann with 55 present. The following papers were given.

(1) ZANE SPIEGEL: Streamflow Contributions from Groundwater (5-min summary)
(2) MADHI S. HANTUSH: Aquifer Tests on Partially Penetrating Wells
(3) G. DEJOSSELIN DE JONG: Vortex Theory for Two-Fluid Flow through Porous Media
(4) HAROLD R. HENRY: Salt Intrusion: Interfaces in Limited Aquifers
(5) J. D. HEM: Some Chemical Factors Related to Artificial Recharge

(6) WILLIAM BACK AND IVAN BARNES*: Field Measurements of Oxidation Potential Related to Iron in Ground Water

The second session convened at 14h 00m, April 27, in the same auditorium, Harold G. Wilm presiding. Ninety members were present; the following papers were read:

(7) GEORGE W. PEAK: Snow Storage Evaporation (5-min summary) (read by W. H. Sammons)
(8) JOHN A. ROBERSON AND DONALD L. BENDER*: The Use of a Dimensionless Unit Hydrograph to Derive Unit Hydrographs for Some Pacific Northwest Basins (5-min. summary)
(9) WILLIAM J. SCHNEIDER: Reduction in Peak Discharges Associated with Reforestation
(10) MANUAL A. BENSON: Areal Flood-Frequency Analysis in a Humid Region
(11) HALLARD B. KINNISON* AND WILBUR D. SIMONS: Factors Influencing Monthly Runoff in the Columbia River Basin
(12) H. C. RIGGS: Rainfall and Minimum Flows

The third session, following the business meeting, convened at 09h 30m April 28, President Langbein presiding. Sixty members were present and the following program was presented:

(13) JAMES L. SMITH: Forest Removal Lessens Hardwood Litter-Humus in Arkansas Ozarks (5-min summary) Presented by C. E. Holscher
(14) C. T. SNYDER: The Pleistocene Lake in Spring Valley, Nevada, and Its Climate Implications
(15) RAYMOND E. LEONARD: Net Precipitation in a Northern Hardwood Forest. Read by H. W. Lull
(16) F. A. HUFF* AND S. A. CHANGNON: Distribution of Excessive Rainfall Amounts over an Urban Area
(17) JOHN W. ROEHL: Sediment Delivery Rates (5-min summary)
(18) F. H. RAINWATER*, C. H. HEMBREE, AND R. B. VICE: Base Network Design for Stream Sediments and Solutes

The fourth session, held in the Reading Room, National Academy of Sciences, convened at 14h 00m April 28, Mr. A. J. Cooper presiding. Fifty members were present, and the following papers were read:

(19) E. G. MILLER: Characteristics of Tide-Affected Flow of the Lower Delaware River
(20) R. B. MARSTON: Free Water Surface Evaporation at a High Altitude Station in the Northern Wasatch Mountains of Utah (5-min summary)
(21) Q. L. FLOREY, L. O. TIMBLIN, JR., AND H. R. MCDONALD*: Evaporation Loss Reduction at Lake Hefner
(22) GORDON E. KOBERG: Effect on Evaporation of Releases from Reservoirs on Salt River, Arizona
(23) ALLAN J. WEST: Snow Evaporation and Condensation

The fifth session held in the same room, convened at 14h 00m, April 29, with 45 members present and M. F. Meier presiding. The following papers were presented:

(24) EDWARD R. LACHAPELLE: Recent Glacier Variations in Western Washington (5-min summary)
(25) S. EPSTEIN, R. P. SHARP*, AND I. VIDZIUNAS: Oxygen-Isotope Relations on the Blue Glacier (5-min summary)
(26) JAMES A. BENDER: Deformation of Excavations in Snow (5-min summary)
(27) MICHAEL A. BILELLO: Formation, Growth, and Decay of Sea Ice in the Canadian Arctic Archipelago (5-min summary)
(28) MARK F. MEIER: Hydrologic Regimen of a Mountain Glacier
(29) C. R. ALLEN, W. B. KAMB, M. F. MEIER, AND R. P. SHARP*: Structures of the Lower Blue Glacier, Washington
(30) AUSTIN S. POST: Sudden Advance of the Muldrow Glacier (read by E. R. LaChapelle)
(31) ARTHUR JOHNSON: Variations in Surface Elevations of the Nisqually Glacier, Mt. Rainier, Washington
(32) HENRY W. ANDERSON: Three Years of 'Operation Wet-Blanket' Progress (read by H. W. Lull)

Meetings adjourned at 12h 00m.

C. C. MCDONALD, *Secretary*

APPENDIX I—Minutes of the Annual Meeting of 1960, Section of Tectonophysics

Vice President Slichter called the meeting to order at 09h 15m on April 29 in the Auditorium of the Department of Interior. There was no business to come before the group at this time and the scientific session began at 09h 18m. The following papers and film were presented (speaker denoted by asterisk).

(1) HOWARD J. PINCUS: Geological Interpretation of Major Ohio Gravity Anomalies
(2) GEORGE S. GERLACH* AND H. LEROY SCHARON: A Regional Gravity Survey of the St. Francois Mountains of Missouri
(3) WARREN HAMILTON: Origin of the Gulf of California

(4) ANIRUDDA DE* AND J. C. MAXWELL: Deformation of Quartz Grains in Sandstone
(5) J. A. MACFADYEN, JR.: Clay as a Model Material in Structural Geology
(6) W. F. BRACE: An Extension of the Griffith Theory of Fracture to Rocks
(7) T. R. MADDEN*, T. CANTWELL, AND A. HAUCK: Electrical Conductivity Structure of the Crust under Massachusetts Determined from Resistivity and Magnetotelluric Measurements

Discussion followed the presentation of each paper, an advantage offered by an uncrowded schedule. The session ended at 12h 05m.

H. R. GAULT, *Secretary*

Meetings of the Geophysical Society of Hawaii

The Geophysical Society of Hawaii, serving jointly as the Mid-Pacific Regional Group of the AGU and the Hawaiian section of the American Meteorological Society, has held a series of meetings as follows: March 24, Gunter Seckel of the Honolulu Biological Laboratory addressed the group on the subject, "The Oceanographic Climate of the Hawaiian Islands Region." May 12, Francis P. Shepard of the Scripps Institution of Oceanography addressed the group on "Submarine Canyons." May 19, David S. Johnson of the U. S. Weather Bureau addressed the group on the subject, "Tiros I—The World's First Meteorological Satellite."

SPECIAL ANNOUNCEMENTS

• THOMAS F. MALONE DESIGNATED NEW VICE PRESIDENT—Because of the increasing pressure of other duties relating to earlier commitments, F. W. Reichelderfer found it necessary to resign as Vice President of the American Geophysical Union at the time of the Annual Meeting. In accordance with the Statutes, the Executive Committee has taken steps to designate Thomas F. Malone to complete Dr. Reichelderfer's unexpired term.

• CONTEMPLATED CHANGE IN TERMS OF OFFICE—At the present time, new officers are elected for triennial periods in the second winter following a meeting of the General Assembly of IUGG. Because of the great importance to AGU of its service as the U. S. National Committee of the IUGG, it is felt imperative that the term of office of an administration should expire on the June 30 following a meeting of the IUGG. Accordingly, the Executive Committee took steps on April 29 to terminate the present administration as of June 30, 1961 (instead of June 30, 1962), and to elect officers for the succeeding triennium this coming autumn, in order that these officers may know of their election this coming January and have two full years to prepare for the succeeding General Assembly. This involves a change in the Statutes, on which the Executive Committee feels there will be concurrence by the membership in order that AGU may be a more effective instrument in its international relationships. Watch your mail for a ballot on this matter and return it promptly.

• THE JOHN A. FLEMING AWARD—Frederick J. Agnich, Chairman of the Special Committee on an Award in Terrestrial Magnetism and Electricity (being renamed the John A. Fleming Award in Geomagnetism and Aeronomy) is undertaking an active campaign to raise $20,000 among members and friends of AGU to bring this long-contemplated Award to fruition. The hope is that this may be implemented in connection with the Annual Meeting of 1961. This is an appeal to you and to any with whom you are associated to send your contributions to this Fund to Mr. Agnich either c/o the office of the American Geophysical Union, or c/o Geophysical Services, Inc., P. O. Box 35084, Airlawn Station, Dallas 35, Texas. Payment should be made payable to the American Geophysical Union for the John A. Fleming Award Fund.

As those of you who are members of AGU of long standing know, Dr. John A. Fleming was the much beloved and very effective General Secretary of the American Geophysical Union from 1925 to 1947. During most of this period, the General Secretary worked without benefit of an Executive Secretary or a substantial office staff and almost singlehandedly built the American Geophysical Union into the organization it became by 1947. In recognition of this and his great stature as a scientist he was elected Honorary President for life in 1947. He prepared a history of the American Geophysical Union that appears in the opening pages of the *Transactions* of February 1954 (a gratis copy is available on application). Dr. Fleming died on July 29, 1956.

For those of you who did not have the privilege of knowing Dr. Fleming, it should perhaps be pointed out that he was indeed a distinguished scientist who for years was Director of the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. As Dr. Vestine wrote in the biography published in the opening pages of the October 1956 issue of the *Transactions*, Dr. Fleming's was the guiding hand from the beginning of this century through almost fifty years that gave Geophysics much of the direction that it has taken actively in the last decade. His vision guided the geomagneticians past the mere recording of the magnetic field to the wider field that had much to do with the recognition of nuclear forces which in turn led to the understanding of atomic fission and fusion. However, techniques that he was instrumental in developing are still used extensively today in geomagnetic survey work. Under his directorship of the Department of Terrestrial Magnetism, the study of Earth currents, the ionosphere, cosmic rays, meteorology, atmospheric electricity, and solar physics received great impetus. Thus Geophysics owes a great debt to Dr. Fleming which in small degree can be paid by the establishment of an important Award in his honor. It is hoped that the present-day heirs to this work will find it possible to give generously to this Fund.

• TWELFTH GENERAL ASSEMBLY, IUGG, TO BE HELD IN HELSINKI, FINLAND, JULY 25-AUGUST 6, 1960—This is the last call for those who desire to attend this meeting to send word promptly to the office of AGU in order that they may be duly registered and go with appropriate accreditation. All seven of the International Associations have arranged extensive scientific programs. Communications should be sent to the American Geophysical Union, 1515 Massachusetts Avenue, N.W., Washington 5, D. C.

• PACIFIC NORTHWEST REGIONAL MEETING—Plans are progressing for the Pacific Northwest Regional Meeting, to be held at the University of Idaho in Moscow, October 19-20, 1960. Calvin C. Warnick, of the University of Idaho, has been designated as Program Chairman, and persons interested in this phase should get into prompt touch with him. The new officers of the Regional Committee are Melvin Ord (U. S. Corps of Engineers, Walla Walla, Washington), Chairman, and Don-

ald Kuehl (U. S. Weather Bureau, Portland, Oregon), Secretary-Treasurer. Other matters relating to the regional activities should be addressed to the appropriate one of the officers.

• PACIFIC SOUTHWEST REGIONAL MEETING—The Pacific Southwest Regional Meeting will be held January 26–27, 1961, at the University of California in Berkeley. The Program Committee consists of Henry W. Anderson, Chairman (California Forest & Range Expt. Station, P. O. Box 245, Berkeley 1, California), C. Robert Elford, Joseph Kaplan, and Jacob B. Wickham. Interested persons should get in touch with Chairman Anderson or one of the members of his Committee. The Local Arrangements Committee has not yet been designated. Watch the October issue for further word concerning details. Eugene N. Bollay (1595 E. Mendocino St., Altadena, California) is Chairman of the Regional Group and W. D. Duthie (U. S. Naval Postgraduate School, Monterey, California) is Secretary.

• ORGANIZATION OF THE COMMITTEE FOR THE NORTH CENTRAL REGION—The North Central Regional Committee has recently been organized with the following officers: Chairman, Athelstan F. Spilhaus (Institute of Technology, University of Minnesota, Minneapolis 14, Minnesota); Vice Chairman, Harry C. Bolon (1020 Morrell Ave., Rolla, Missouri); and Secretary-Treasurer, Joseph W. Howe (Department of Mechanics and Hydraulics, University of Iowa, Engineering Bldg., Iowa City, Iowa). The other members of the Regional Committee are Rudolph A. Black, Wayne L. Decker, Philip W. Kenworthy, Martin E. Nelson, Robert J. Pafford, Jr., and Robert H. Shaw. Members in the Region interested in assisting in the development of regional activities should get into touch with the officers or members.

• FORTY-SECOND ANNUAL MEETING—The Forty-Second Annual Meeting of the American Geophysical Union will be held in Washington, D. C., April 19–22, 1961 (Wednesday to Saturday, inclusive), in the week preceding the meeting of the National Academy of Sciences, tentatively set as April 24, 25, and 26. Watch SPECIAL ANNOUNCEMENTS for further word.

NATIONAL ACADEMY OF SCIENCES

Number 34 • April 1960

IGY BULLETIN

A monthly survey of programs and findings of the International Geophysical Year and the International Geophysical Cooperation–1959 as related primarily to United States programs.

Seismic Crustal Studies During the IGY

Part II: Continental Program

The following report is based on material compiled by G. P. Woollard, of the Department of Geology, University of Wisconsin. Bulletin No. 33 *outlined the organization of the IGY Seismology Program, reviewed the basic techniques used, and presented results of the marine program; the present report contains results of the continental program.*

Measurements of continental crustal structure were carried out in five areas during the IGY: the central "shield" region of exposed crystalline "basement" rocks and very ancient (pre-Cambrian) sedimentary rocks in the Great Lakes region of the United States; the buried shield area near the head of the Mississippi embayment in the southern United States; the high plateau of central Mexico; the Andean high plateau of South America; and the adjacent Andean foothill region. (See Figure 1 for locations of seismic profiles in North America.)

The major U. S. institutions taking part in the continental seismic program were the University of Wisconsin and the Department of Terrestrial Magnetism of the Carnegie Institution of Washington. In addition, scientists, universities, and IGY committees of Canada, Mexico, Chile, and Peru cooperated in some studies.

Techniques

The basic techniques used by both the Department of Terrestrial Magnetism and the University of Wisconsin were the same, but their recording procedures varied somewhat. The Department of Terrestrial Magnetism group recorded partial profiles along several azimuths around the shot sites. (See *Bulletin No. 11*, Figure 2.) The University of Wisconsin investigators recorded essentially along a single azimuth laid out so as to minimize the effect of possible changes in crustal structure, as indicated by gravity-anomaly patterns and geological evidence at the surface. Another difference was that the University of Wisconsin group made detailed measurements at close ranges in order to determine the effect of the surface geology on the seismic results, whereas this factor was disregarded in the Department of Terrestrial Magnetism measurements. The procedure adopted depended upon type of area studied, accessibility, frequency of shots, and the facilities and time available.

The Department of Terrestrial Magnetism used large blasts set off in connection with local mining operations. The University of Wisconsin seismologists exploded their own charges in the Great Lakes area, and used quarry and mining operation blasts in the other areas studied. Measure-

ments by both groups were carried out to distances beyond 300 kilometers from the shot points in order to obtain first P-wave arrivals refracted from the underlying mantle rock.

United States-Great Lake Region: In this area, two seismic profiles were made approximately at right angles to each other (see Fig. 1), one extending southwest from Keweenaw Peninsula, Michigan, into western Wisconsin, and the other southeast from Apostle Island, in Lake Superior, into south-central Wisconsin. The US Coast Guard collaborated in the experiment by making a ship available so that explosives could be set off under water; this materially reduced the amount of explosive required and gave much better energy coupling than could be obtained by explosions on land. Charges up to 1500 lbs were exploded in these studies; explosions of 750 lbs of nitramon could be detected at distances greater than 275 kilometers.

The Keweenaw Peninsula profile is aligned parallel to the geologic strike (direction of trend of bedrock formations with respect to a horizontal surface) and to the pattern of the gravity anomalies in northern Michigan and western Wisconsin. The crustal structure found in this region consisted of approximately 1.5 kilometers of material having a velocity of 4.7 km/sec overlying material with a velocity of 6.3 km/sec. The latter extends to a depth of 36 kilometers, where the mantle, with a

Fig. 1. *Seismic Profiles in North America During the IGY. The Calgary and Ripple Rock profiles were part of the Canadian IGY program; the Great Salt Lake and Nevada measurements, by the University of Utah and the US Government, respectively, were not in the IGY program but are of interest because they help fill in the crustal-structure picture for North America; all other profiles were part of the US-IGY program.*

velocity of 8.05 km/sec, was found. No intermediate layering was detected.

The surface rocks are all crystalline, for the most part consisting of basalt with some gabbro and granitic schist and gneiss. Gravity measurements in this region indicate an anomaly (Bouguer) of +15 milligals, which might be interpreted as evidence of a thinner than normal crust. (A gravity anomaly is a deviation, either positive or negative, from expected values for a particular geographic location. In the Bouguer anomaly, a correction is made to account for the station's altitude above sea level and the intervening rock mass.) However, the anomaly appears to be related principally to the basic surface rocks. The crust may also contribute to the anomaly as the velocity of 6.3 km/sec is somewhat higher than the 6.1–6.2 km/sec usually found in this region, possibly indicating material of slightly greater density.

The Apostle Island profile is a reversed profile—one in which recordings are made in both directions from shot points at opposite ends of the profile. The profile crosses a major structural dome in the surface rocks composed almost entirely, at the surface, of granitic crystalline rocks. At the north end of the profile, where the explosive was detonated, pre-Cambrian clastic sedimentary rocks predominate. The gravity pattern shows a pronounced "low" (negative anomaly) in the area, and along the profile there is a negative gradient toward the south. The mean anomaly along the profile is —40 milligals. The north end of the seismic section shows about 2 kilometers of material having a velocity of 3.5 km/sec at the top; this is probably the pre-Cambrian sediments. Beneath this is 3 kilometers of material having a velocity of 5.2 km/sec, and beneath this, in turn, the crust, with a velocity of 6.15 km/sec, extends down to the mantle, lying at a depth of 37 kilometers. The mantle velocity was 8.15 km/sec.

On the south end of the profile, in the vicinity of Wausau, Wisconsin, the section shows surface material (granite) with a velocity of 5.2 km/sec, which changes to a velocity of 6.15 km/sec at a depth of 1 kilometer. No intermediate layering is evident and the mantle, with a velocity of 8.15 km/sec, is indicated at a depth of 36.6 kilometers.

Arkansas Profile: This profile, based on quarry blasts in the vicinity of Little Rock, extends to the Cape Girardeau area of Missouri, on the Mississippi River. The entire area is characterized by slight positive Bouguer gravity anomalies, and it has been noted for many years that earthquake-wave arrivals in this area were earlier than would be predicted from normal continental travel-time tables.

Although the shot point was located in an area of crystalline syenitic rocks, most of the profile extended over an area of increasingly thick sedimentary rocks of Paleozoic (geologic era: approximately 180–510 million years ago), Cretaceous (geologic period: 60–125 million years ago), and younger age. The seismic results indicated an upper layer, 2 kilometers thick, of material with a velocity of 4.65 km/sec, underlain by 10 kilometers of 5.5 km/sec material. Beneath this is crustal material having a velocity of 6.9 km/sec down to a depth of 43 kilometers, where the mantle, with a velocity of 8.15 km/sec, was encountered. On the basis of magnetic and well data, it is clear that the 5.15 km/sec material constitutes an upper layer in the crust rather than carbonate sedimentary material such as is observed at the surface to the north of the profile.

It is significant that this deep crustal section occurs in an area of low elevation rather than beneath a mountainous or plateau region, where a thickening of the crust would be expected. The high density of about 3.0 gm/cm^3, implied by the velocity of 6.9 km/sec, explains the positive gravity anomaly value and the lack of an appreciable gravity low. (Note: Since crustal material is less dense than mantle ma-

terial, gravity lows are usual where the crust is thick—i.e., extends deep into the mantle—and highs occur where the crust is thin.) The high crustal velocity also explains the early earthquake arrival times in the area.

Plateau of Mexico Profile: This profile is based on open-pit-mining blasts near Durango, Mexico. The profile extends southward from the shot point, paralleling the Sierra Madra Range and the gravity anomaly pattern. Near-surface detail was obtained by firing a reverse spread over the first 20 kilometers of the profile. (The reverse spread consisted of locating the geophones near the original shot point and exploding a small charge about 20 kilometers away along the line of the original profile.) As the mean gravity anomaly value is about —200 milligals, a thick crustal section was anticipated. The surface rocks are largely volcanic tuffs, but there is reason to believe that these may in places be underlain by Jurassic (geologic period: 125–150 million years ago) or Cretaceous limestones, which crop out farther south.

The seismic results indicate a surface layer having a velocity of 3.0 km/sec and about 0.5 kilometers thick underlain by a layer about 3.5 kilometers thick having a velocity of 4.9 km/sec. This in turn is underlain by a layer in which the velocity is 6.0 km/sec. Two interpretations appear possible in determining the thickness of this layer and of underlying deeper layers. The interpretation preferred by the University of Wisconsin investigators, based on a theoretical analysis of the data concerning times for critical reflections from the base of the crust, is that the material with a velocity of 6.0 km/sec is 28.9 kilometers thick. Beneath this is a basal layer, 11 kilometers thick, with a velocity of 7.6 km/sec. Beneath this, in turn, is mantle rock, with a velocity of 8.2 km/sec. The total thickness of the crust, in this interpretation, is 43.8 kilometers.

In the alternate interpretation, the 6.0 km/sec layer is 16.2 kilometers thick and is underlain by two basal layers. The velocity of the upper basal layer is 6.4 km/sec and its thickness is 15.3 kilometers; the velocity of the lower basal layer is 7.6 km/sec and its thickness is 8.8 kilometers. The total crustal thickness, according to this interpretation, is 44.2 kilometers.

Toquepala, Peru, Profiles: These profiles were based on mining operation blasts at the Toquepala Copper Mine about 60 miles northwest of Tacna (see *Bulletin No. 11*). Recording was carried out along 10 azimuths on profiles of varying lengths. Although explosive shots up to 50 tons were used, it was not possible to obtain either refracted first arrivals or reflections from the base of the crust beneath the altiplano proper. (The altiplano is the great high plateau—12,000 to 16,000 feet above sea level—that supports the Andes Mountains.) First arrivals from the base of the crust, however, were obtained in the flank area of the altiplano along the profiles paralleling the structural "grain" of the mountains.

The apparent velocity layering, from the top of the crust downward, is as follows: 5.3 km/sec; 6.2 km/sec; a suggestion of a 6.7 km/sec layer; and the mantle, with 8.2 km/sec. On this basis, the computed thickness of the crust is about 46 kilometers. If second arrivals (waves refracted from deep layers and detected at ranges short of the critical range for first arrivals) are used in the altiplano region proper, a depth of the order of 65 kilometers is suggested for the base of the crust beneath the high plateau. From the top down, the crustal structure indicated consists of 4.1 kilometers of 5.3 km/sec material, 21.2 kilometers of 6.2 km/sec material, and 39.6 kilometers of 6.7 km/sec material, overlying the mantle.

Chuquicamata, Chile, Profiles: This area, like the preceding one, lies on the high Andean altiplano, and the shot site, also a mine, is about 125 miles northeast of Antofagasta. As in the Toquepala profile, it was

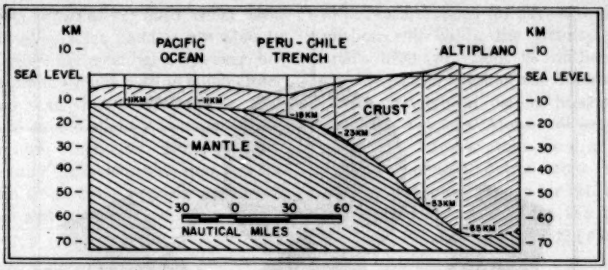

Fig. 2. *Crustal Profile from Altiplano Westward Across Coastal Region, Peru-Chile Trench, and Part of South Pacific. Compiled from data obtained in Carnegie Institution of Washington continental seismic studies and in Scripps Institution of Oceanography marine seismic studies.* (*See* Bulletin No. 33.)

not possible to obtain first arrivals from the base of the crust beneath the altiplano, although first arrivals were obtained to the south over the flank area.

The velocity structure observed showed surface material with a velocity of about 5.5 km/sec; an underlying layer with velocities of 6.0 km/sec to, possibly, 6.4 km/sec; and, indicated definitely by first arrivals, a 7.0 km/sec basal layer overlying the mantle, which has a velocity of about 8.0 km/sec in this region. On the basis of this structure, an over-all crustal thickness of about 56 kilometers was computed for the mountain-flank area. If second arrivals are used, a thickness of 70 kilometers is found beneath the altiplano. Without the first arrivals, however, this value, as well as that for the altiplano of Peru, cannot be considered well substantiated. The crustal structure indicated, from top down, consists of 6 kilometers of 5.5 km/sec material, 28.4 kilometers of 6.35 km/sec material, and 35.9 kilometers of 7.0 km/sec material, overlying the mantle. (A more complete report on the South American studies is given in *Carnegie Institution of Washington Year Book 57*, Dec. 19, 1958.)

As the Scripps Institution of Oceanography measurements in the Peru-Chile Trench offshore from Antofagasta, Chile (see *Bulletin No. 33*), lie immediately adjacent to the Chuquicamata study, it is possible to draw a crustal profile across the continental boundary, as shown in Figure 2. This profile is in excellent agreement with that which would be deduced from gravity studies.

Pioneer V Space Probe

1960 Alpha (Pioneer V), the fourth United States scientific space probe, was launched at approximately 8:00 am EST, March 11, 1960, from Cape Canaveral, Florida. (Space probes are now included in the Greek letter system used, on the basis of astronomical precedents, to designate artificial earth satellites.) The probe, instrumented to measure cosmic-rays and other radiations, magnetic fields, and microme-

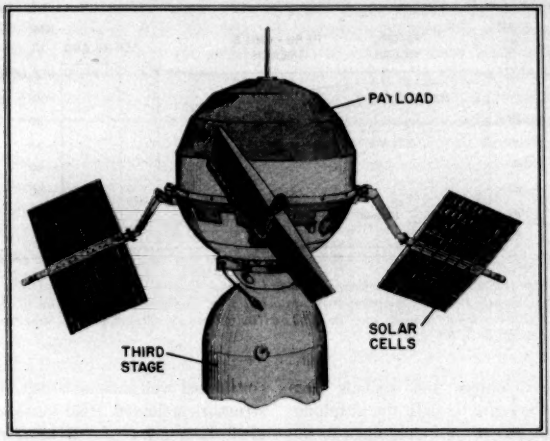

Fig. 3. *Pioneer V Space Probe.*

teorite intensity in space, and carrying solar-powered radio equipment capable of transmitting over vastly greater distances than ever before, entered a heliocentric orbit between the orbits of Earth and Venus.

The Space Science Board of the National Academy of Sciences immediately sent a message to the international Committee on Space Research (COSPAR) for transmission to all COSPAR participants, announcing the launch and giving details on 1960 Alpha and its instrumentation. Data accumulated by the probe will be deposited in the World Data Centers established during the IGY, and will be forwarded to COSPAR; the data will thus be made available to scientists throughout the world.

1960 Alpha is a project of the National Aeronautics and Space Administration, with technical assistance by the Air Force Ballistic Missile Division. Under contract to AFBMD, Space Technology Laboratories provided payload packaging and system integration. More than 50 other scientific and industrial organizations participated in the Pioneer V program.

Probe Characteristics

1960 Alpha (Pioneer V) is the third in a series of "paddlewheel" payloads. (See Figure 3.) The first was the satellite 1959 Delta (Explorer VI), launched into a high, elliptical orbit on August 7, 1959; the second, intended as a space probe, failed shortly after launch on November 26, 1959. The spheroidal Pioneer V probe is 26 inches in diameter, 29 inches deep, and slightly flattened on the bottom. Its aluminum skin is 1/16 inch thick and painted with an absorptive-emittive temperature control paint. The total weight of the payload is 94.8 pounds: the shell and internal structure weigh approximately 10 pounds; the transmitter, power supply, and electronics about 50 pounds; and the experimental instrumentation about 35 pounds.

As with 1959 Delta, four vanes, or "paddles," of power-generating solar cells jut from the waist of 1960 Alpha. The probe's paddles are somewhat smaller than those of 1959 Delta, measuring about 18 $\times$ 14 inches and carrying a total of 4800 solar cells whereas the 20 $\times$ 20 paddles of 1959

Delta carry a total of 8000 cells. 1960 Alpha's smaller solar paddles are able to absorb 30-40% more sunlight, however, because the probe's flight path is much closer to the sun than that of 1959 Delta. The paddles are canted slightly to expose them to a maximum of sunlight. When the paddles are fully extended, the span of the probe from tip to tip of opposite paddles is about four and one-half feet.

Launching and Flight Data

1960 Alpha was launched into its orbit around the sun by a three-stage Thor-Able IV rocket standing approximately 90 feet high and weighing more than 105,000 pounds. This is the same launching vehicle used to put 1959 Delta into a 26,400- by 157-mile orbit around the Earth; an earlier version propelled the Pioneer I space probe to an altitude of approximately 70,700 miles. (*Bulletin No. 18* describes the essentially similar Pioneer I vehicle.)

Although 1959 Delta and 1960 Alpha are designed in the same pattern, the total payload weight of the latter was held approximately 47 pounds lower than that of the former in order to achieve a payload velocity about 3000 mph greater. The velocity reached by 1960 Alpha at third-stage burnout was 24,869 mph, about 575 mph faster than the minimum required to escape from the Earth's gravitational attraction and enter a heliocentric orbit.

On the basis of preliminary data obtained in the first few days after launch, 1960 Alpha will have an orbital period of about 311 days, compared with 365 days for Earth and 225 for Venus. The circumference of 1960 Alpha's orbit around the sun is approximately 528,000,000 miles. The space probe's mean velocity is approximately intermediate between that of the Earth (67,000 mph) and that of Venus (78,000 mph). At perihelion, its nearest approach to the sun, the probe will be about 74.9 million miles from the sun and about 8 million miles outside the orbit of Venus. This point will be reached about 151 days after launch. Aphelion will be in the vicinity of the Earth's orbit, or about 93 million miles from the sun. Because of the differences in velocity and orbital period, however, the possibility that 1960 Alpha will eventually re-enter the Earth's atmosphere and burn up is very remote. Astronomers estimate that this would not happen for roughly another 100,000 years, and in the case of Venus, not for another 1,000,000 years. (See Figure 4.)

Experiments

1960 Alpha is instrumented primarily to measure radiation in space, including cosmic rays and the radiations associated with solar activity; magnetic fields in space; and micrometeorite activity. The probe also carries an eight-ounce "aspect indicator," a photoelectric cell developed by STL to take fixes on the sun, thus making it possible to relate the radiation and magnetic measurements directionally to the sun. Temperature measurements are also being made, and the radio equipment used represents an experiment in extremely long-range space communication.

High-Energy Radiation: Instrumentation to measure the intensity of high-energy radiation between the orbits of Earth and Venus was developed for 1960 Alpha by the University of Chicago. The instrumentation, a triple-coincidence proportional-counter arrangement, consists essentially of a bundle of argon-filled cylinders, six of them arranged around the seventh. The entire bundle, including a thin lead shield to screen out the lower-energy particles, is two inches square. Particles striking the counter ionize the gas in the tiny cylinders, causing electrical "blips" to be recorded as they penetrate one or more cylinders. The number of cylinders a particle can penetrate depends on its energy and direction.

This experiment may make it possible to

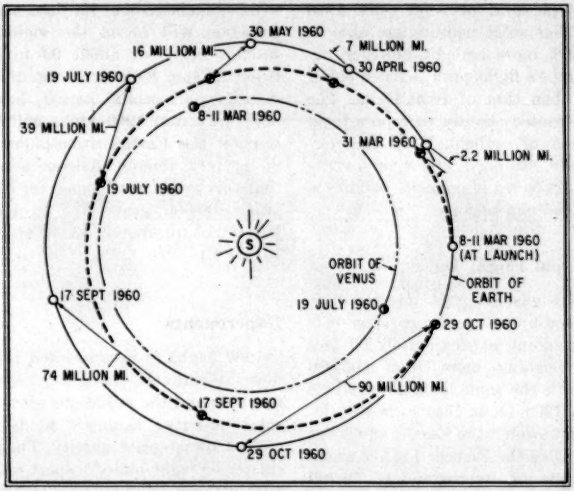

Fig. 4. *Approximate Orbit of Pioneer V (heavy dash line) and the Probe's Position on Various Dates Relative to the Positions of Earth and Venus.*

determine whether cosmic rays are produced by the sun and to compute their time of flight from sun to Earth. Clouds of particles coming from the direction of the sun may first be detected by the probe and may subsequently again be detected near the Earth—possibly by orbiting satellites—permitting calculation of their flight-time over the intervening distance. Measurements in deep space, away from the Earth's influence, may also help to establish whether the 11-year cosmic-ray cycle (which shows an inverse relationship to the 11-year sunspot cycle) is caused by some effect associated with proximity to the Earth or whether it is actually caused by varying intensity of particle emission from the sun. Also, this experiment may provide some knowledge as to whether high-energy particles coming from the sun are accelerated on the sun or by some process in the Earth's magnetic field.

Total Radiation Flux: An experiment consisting of an ionization chamber and a Geiger-Mueller tube, designed and provided by the University of Minnesota, is measuring the total flux of medium-energy radiation encountered by 1960 Alpha. The Geiger-Mueller tube counts the number of medium-energy electrons and protons penetrating the tube, and the ionization chamber provides information on particle energies. The instruments, weighing about two pounds, are packaged in a four-inch-square box.

This experiment is designed primarily to study the clouds of "plasma"—charged particles emitted by solar flares and causing magnetic and other disturbances at the Earth—and other charged particles from the sun. As with the cosmic-ray experiment, solar plasmas encountered by the probe may subsequently be recorded again upon their arrival at the Earth.

Magnetic Fields: The probe carries a one-pound search-coil magnetometer, developed by STL. This instrument is de-

signed to determine the strength and direction of magnetic fields in space. Such determinations are closely related to the radiation studies. Measurements of magnetic fields associated with the plasma clouds are of special interest. Also of interest are measurements of magnetic fields in the tenuous solar corona, which is believed to extend beyond the orbit of the Earth.

Micrometeorites: As do most satellites and space probes launched thus far, 1960 Alpha carries a device to record micrometeorite impacts. The unit, developed by the Air Force Cambridge Research Center, is designed to measure the number and momentum (mass $\times$ velocity) of meteoritic dust particles striking the probe. A diaphragm about twice the size of a playing card is mounted on the payload skin and connected to a microphone inside the probe. The noise of an impact on the diaphragm is translated into an electrical impulse which is recorded and later relayed to Earth. The entire unit weighs less than one pound.

Temperatures: Five tiny thermistors, two on the paddles outside the probe's shell and three within the payload, are measuring temperatures. It was expected that the temperature-control paint pattern used on the probe would maintain interior temperatures between about 55° F and 80° F.

Radio Equipment

The Pioneer V space probe carries two ultra-high-frequency (UHF) radio transmitters, operating on a frequency of 378 megacycles per second. One, a 5-watt transmitter, is being used to "read out" experimental data during the first few million miles from the Earth, until the probe has traveled beyond its maximum range. Then, on command from the Earth, it will become a "booster" amplifier for the other, much-more-powerful transmitter.

The second transmitter, with a power of 150 watts, is expected to continue sending until the probe is about 50,000,000 miles from the Earth. (Previously, Pioneer IV had transmitted over a record distance of 407,000 miles.) At that time, approximately five months from launch, 1960 Alpha will have been transmitting back to Earth scientific measurements of space conditions over about 250,000,000 miles of its orbit. The probe will then move beyond the range of the high-power transmitter. In about 1963, the probe may again come within the 50,000,000-mile range as it overtakes the Earth from the other direction. It is hoped that the transmitters will still be operational at that time and that it may again be possible to obtain scientific data.

Because of the great power requirements of the 150-watt transmitter, communication with the probe is effected for only 15 to 30 minutes out of each five hours. During the intervening periods, the solar cells on the paddles recharge the nickel-cadmium batteries. Commands are sent to the payload in complex multidigit code. A command radio receiver, in operation at all times, routes the inbound signal to a command box which unscrambles the signal and closes circuits so that the desired command can be executed. When the transmitter is not sending, all experiments continue to function and data is stored in small electronic accumulators, or "memory units." These record a given experiment's total activity, very much as does the total mileage register on an automobile speedometer. When the transmitter is in operation, the totals are sent first, then the transmitters send experimental data as it is acquired.

In addition to testing radio communications over vast distances in space, a by-product of the long-range transmissions may be the improvement of determinations of space distances. Distances within the universe are computed primarily by applying the basic laws of physics governing bodies in motion and plotting the positions of nearer celestial bodies against comparatively stable, distant stars. The basic unit of measure used by astronomers is the Astronomical Unit (AU), which is the mean

distance between the Earth and sun—93,000,000 miles. This measurement is accurate only to within about 50,000 miles, a margin of error important in computations for future space missions though small relative to the tremendous distances in intragalactic space beyond the solar system and in extra-galactic space. By "triangulation" between Earth and the various points in space from which the probe's signals are received, scientists may be able to compute space distances more accurately.

Tracking

The principal stations for reception of data from 1960 Alpha are at Jodrell Bank, Manchester, England; Millstone Hill, New Hampshire; South Point, Hawaii; Singapore, Malaya; and Cape Canaveral, Florida. All of these stations are linked on a teletype circuit controlled from STL's Space Navigation Center, in Los Angeles.

The University of Manchester's 250-foot parabolic radio telescope, plus additional helical antennas, at Jodrell Bank, has both command and telemetry reception functions. The 85-foot parabolic dish at Millstone Hill, operated by Massachusetts Institute of Technology's Lincoln Laboratories, was used for radar tracking during launch, and subsequently has received telemetry data. Both command and telemetry reception functions are performed by the STL 60-foot parabolic dish and helical antenna at South Point. At Singapore, small antenna arrays are operated by STL for telemetry reception. A variety of antennas, also operated by STL, at the Atlantic Missile Range, Cape Canaveral, were used to send steering commands to the second stage during launch and for early data reception.

The first radio acquisition of 1960 Alpha's signal was made by the Jodrell Bank radio telescope at 8:13 am EST, March 11, shortly after launch. This first transmission continued until 8:30 am. At about 8:00 pm EST, March 13, the probe was interrogated and data were transmitted from a distance of 409,060 miles, surpassing the previous record of 407,000 miles set by Pioneer IV. Transmission at a distance slightly greater than 1,000,000 miles was achieved at 2:00 am EST (0700 GMT), on March 18, 1960. Since then, 1960 Alpha has continued to radio back to Earth scientific data of space conditions from ever-increasing distances.

Ice Fabrics on Blue Glacier

The following report is based on material prepared by W. B. Kamb, of the Division of Geological Sciences, California Institute of Technology. A more detailed account was published in the Journal of Geophysical Research, *November 1959.*

As part of the series of IGY studies conducted by California Institute of Technology glaciologists on Blue Glacier, in the Olympic Mountains of Washington State, a number of ice samples were collected for ice fabric analysis. (*Bulletin No. 11* describes the Blue Glacier project and presents early results.) Ice fabrics—the patterns produced by the spatial relations and preferred orientations of ice crystals—reflect the patterns of stress and strain related to glacier flow. Thus, these studies constituted an integral part of the over-all Caltech program of analysis of the mode and mechanism of flow in the relatively simple ice tongue of Blue Glacier.

Blue Glacier is situated on the north slope of Mount Olympus, in Olympic National Park (see Fig. 5). The glacier origi-

Fig. 5. *Blue Glacier, Olympic Mountains, Washington. Structural mapping by C. R. Allen, M. F. Meier, W. B. Kamb, and R. P. Sharp.*

nates in two accumulation basins on the upper part of the mountain. From these basins, three ice streams flow over a steep ice fall to merge into a single valley glacier more than half a mile wide and terminating almost two miles from the base of the ice fall. This report is based on fabric analysis of ice samples collected in the lower part of the glacier—below the firn limit—which, in late summer when the collections were made, lies about one-third of the way from the ice fall to the glacier terminus. (Firn is compact, granular snow that has lasted through at least one summer. The firn limit marks the lower margin of the accumulation area.)

The field data and ice-samples were collected in August 1957 and August 1958. Fabric analysis of the glacier ice was carried out by W. B. Kamb with the help and advice of R. P. Sharp, director of the Blue Glacier project.

Technique of Fabric Analysis

Glacier ice is a monomineralic rock that has been metamorphosed while subjected to stresses related to the movement of the glacier under the influence of gravity. As with other metamorphic rocks, ice is entirely recrystallized in this process. It is, therefore, possible to apply the geologic technique of petrofabric analysis to the study of glacier-ice fabrics.

The technique involves, first, the collection of ice samples from various parts of the glacier. From each sample, many "thin-sections" are cut and mounted on slides for examination by means of a universal stage —a stage which can be rotated about three mutually perpendicular axes so that the thin-section can be brought into any position desired. A large number of crystals from each sample—usually more than 100 and often several hundred—are then examined and the orientations of their optic axes are plotted on "point diagrams." (The optic axis is that direction in an anisotropic mineral along which no double refraction occurs. In a hexagonal mineral, such as ice, the optic axis corresponds to the *c*-crystallographic axis, the symmetry axis perpendicular to, and differing in length from, the three equal symmetry axes lying in the plane of the hexagonal cross-section of the crystal.)

To construct a point diagram, each crystal is imagined to be at the center of a sphere. A line representing the *c*-axis of the crystal is projected to the point where it strikes the lower hemisphere of the sphere. (The upper hemisphere may also be used, but the lower is frequently preferred.) This point is then projected to a corresponding horizontal circular plot—the point diagram (see Fig. 6). When the orientations of a sufficiently large number of crystals from a sample have been similarly plotted, the ori-

entation patterns of the ice crystals in the sample become apparent. From the point diagram, a contoured diagram (Fig. 6) may also be constructed, showing, in terms of percentages of the total number of crystals measured, the density distribution of the points plotted. Highs in point density are termed *maxima;* lows are termed *minima.*

The orientations of the samples with respect to the glacier are carefully determined at the time of collection, and the orientations of the thin sections are likewise determined when they are cut from the samples. Thus, ice fabrics can be related to structures and to stress and strain patterns in the glacier.

For the present study, Kamb devised a new procedure for preparation of the point, or density, diagrams which also permits statistical inferences to be drawn directly from the diagrams. The new procedure is explained in detail in the fuller report in the November 1959 issue of the *Journal of Geophysical Research.*

Glacier-Ice Textures

An understanding of the relationship of ice fabrics to ice textures is essential to an analysis of the flow mechanics of a glacier. Three textural types are common in valley glaciers: coarse bubbly ice, coarse clear ice, and fine ice.

Coarse bubbly ice appears to be the most abundant ice type in temperate-zone glaciers. This type of ice is composed of crystals 1-6 centimeters in diameter, very elongate, sinuous, or branching in shape, and up to 20 centimeters or more in length. The texture formed by the interdigitation of these complexly shaped crystals holds together even when individual crystals are loosened by melting along crystal boundaries.

Numerous spheroidal bubbles containing air and water vapor occur in this type of ice, mostly within individual crystals. The bubbles are 1–2 millimeters in diameter and tend to form indistinct layers, or "bands," resulting in a weakly foliated structure in the ice. Sharply defined bubble layers also occur. However, these layers, 3–10 centimeters thick and containing much greater concentrations of bubbles than the indistinct layers, are relatively uncommon. The crystalline texture of the coarse bubbly ice is not affected by the bubble-layer foliation; individual crystals extend through both bubble-rich and bubble-poor zones without apparent discontinuity.

Coarse clear ice occurs in distinct structural situations in the glacier. This ice type consists of a clear, transparent aggregate of very coarse crystals, 2–12 centimeters in diameter and nearly bubble-free. The typical interlocking texture is similar to that of coarse bubbly ice. Coarse clear ice is found in large zones of stagnant ice at the glacier margins; as "blue bands," or thin layers (1–6 centimeters) intercalated with coarse bubbly ice in the foliated structure of the glacier; as irregular pods and masses within fine ice, generally elongated parallel to the foliation; and, less commonly, as irregular pods within coarse bubbly ice.

Fine ice, composed of crystals 0.5–2 millimeters in diameter and usually less than 4 millimeters in length, occurs in 2- to 15-centimeter-thick layers intercalated with coarse bubbly ice and coarse clear ice, forming the foliated structure visible almost everywhere on the glacier surface. The individual crystals, which are either equidimensional or discoid in shape, do not interlock as do those of the coarse-grained ice; hence, they separate readily as melting occurs. Fine ice contains small bubbles, less than 1 millimeter in diameter, scattered throughout. The bubbles show weak to strong segregation into bubble-rich and bubble-poor layers paralleling the foliation. Fine ice is clear, dense, and impermeable, except where melting has occurred. Individual crystals of fine ice appear to be shortened in the dimension perpendicular to the foliation plane.

Blue Glacier Fabrics

Fabric analyses were made for samples from nine localities on Blue Glacier (see Fig. 5). At some localities, several separate fabric studies were made—in particular for fine ice and adjacent coarse bubbly ice, for comparison purposes. This report considers only these two ice types, with emphasis on their relations to the stresses under which they develop and to the origin of ice fabrics in general. (The relation of Blue Glacier ice fabrics to the over-all structure of the glacier will be discussed in another report by members of the Caltech Blue Glacier project.)

Fine Ice: The fine-ice fabrics observed on Blue Glacier are remarkably simple and consistent. The fabrics measured in all samples show essentially the same pattern—a broad maximum in the density of *c*-axes

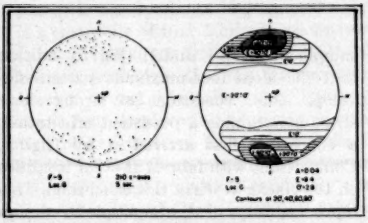

Fig. 6. *Point and Contoured Diagrams of Fine-Ice Sample F-5, from Locality G. Compass directions and up-down direction of sample relative to its position in the glacier are indicated. (A, E, and σ are factors used in Kamb's new method of preparing contoured diagrams so as to show the statistical significance of the density distribution. See* Journal of Geophysical Research *report for details.)*

centered about the pole of the foliation plane, regardless of the attitude or structural position of the foliation. (The pole of the foliation plane is the direction perpendicular to that plane; it is projected onto the fabric diagram in the same manner as are the crystal axes.) Figure 6 shows point and contoured diagrams for fine ice from sample locality G, near the firn line of the glacier.

The fact that the single broad maximum in the density of *c*-axis orientations in fine ice occurs repeatedly in specific structural situations in the glacier suggests strongly that this pattern is a universal feature of fine ice and may, therefore, be expected in any fine-ice layer in the glacier. It appears that the occurrence of this pattern in temperate glaciers has not been reported previously, although a similar pattern was observed by G. P. Rigsby in the ice of a polar glacier in Greenland and in the Greenland ice sheet. (Polar ice is, in general, relatively fine-grained throughout.) Unlike the maximum in polar ice, which is sharp and narrow and contains *c*-axis densities greater than 30% within only 1% of the diagram area, the maximum in temperate fine ice is typically very broad and uniform and densities do not exceed 5% in 1% of the area. Moreover, temperate fine ice contains more of the finest grains (less than 1 millimeter) than does polar ice.

The characteristic flattening of individual fine-ice crystals in the direction perpendicular to the foliation plane is reflected by a subtle banding, which can be seen on "weathered" portions (those exposed to sunlight) of the fine ice. This appears to be the first time a well-defined dimensional orientation has been recognized in glacier ice.

Coarse Bubbly Ice: For each locality at which fine-ice samples were taken for analysis, samples of adjacent coarse bubbly ice were also collected. In general, the coarse bubbly ice fabric was found to have several maxima in the density of *c*-axis orientations. Some of these "multiple-maximum" fabrics are of the four-maximum type found earlier by Rigsby, but others are unrelated to this fabric type. Ideal four-maximum fabrics, in which the maxima form a diamond-shaped pattern, have been found consistently in ice that has been subjected to simple-shear strain for long periods of time. (Simple shear strain is unidi-

rectional strain applied to a body in the plane of one of its faces.) This report considers only the four-maximum fabrics of Blue Glacier. (See Figure 7.)

The problem of determining the origin of these coarse-ice fabrics requires a comparison between theoretically or empirically predicted fabrics and fabrics developed naturally under well-defined stress conditions. It was not possible to make such a test using fabrics previously reported, since either the precise stress situations at the time of recrystallization of these fabrics were unknown or the fabric patterns themselves were anomalous. In the present study, therefore, coarse bubbly ice samples were obtained at localities on Blue Glacier specifically chosen to provide the needed information. These localities (see Fig. 5, localities B, E, and H) are at the inner edge of the zone of marginal crevassing, where rapid shearing is taking place and the stress situation is well defined.

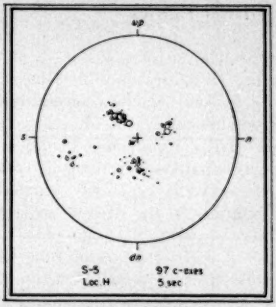

Fig. 7. *Fabric Diagram for Sample S-5, Coarse Bubbly Ice from Location H in the Zone of Strong Foliation near the Western Margin of the Glacier. The diamond-shaped four-maximum pattern is clearly shown. Dots represent crystals with cross-sectional areas of 1–3 square centimeters; small circles, 3–6 cm²; intermediate circles, 6–12 cm²; and large circles, 12–30 cm². Pole of the foliation plane is at w.*

Comparisons of fabric diagrams for ice from various parts of the glacier show that the multiple-maximum fabrics are consistent with respect both to the extent of development of the maxima and to the geometry and orientation of the entire fabric pattern in relation to the stress pattern under which it develops. Significantly, however, the orientations of the several maxima in a particular fabric relative to each other were found to be more consistent than the orientation of the patterns as a whole with respect to the foliation plane. This confirms earlier observations by Rigsby. It also appears that the relative orientation and degree of development of the maxima may be more strongly influenced by local conditions than by the over-all stress situation and foliation pattern. This effect may result from rotational movements in the glacier that vary locally relative to the foliation plane. Such rotations might be superimposed on the ice by shearing motions occurring after the main fabric features had developed.

Consistent fabric patterns observed at sample localities E and H (Fig. 5) indicate that the ideal four-maximum pattern develops under conditions of strong shear stress maintaining a persistent orientation, a conclusion first arrived at by Rigsby. Comparisons with fabrics at other localities on the glacier reaffirm this conclusion. This reproducibility of the multiple-maximum fabrics under given stress situations in various parts of the glacier, a statistical matter of greatest importance in establishing the origin of these coarse-ice fabrics, had not been so clearly demonstrated in previous studies. In addition, detailed interpretation of the fabric diagrams in terms of the orientations of associated stress vectors indicates that the basic fabric pattern evidently originates fairly deep within the glacier.

It also appears that the long axis of the "diamond" (see Fig. 7) approximately parallels the stress vector acting across the persistent plane of maximum shear stress. In addition, a differing degree of development of "near" and "far" maxima is strongly evident in the Blue Glacier fabrics, al-

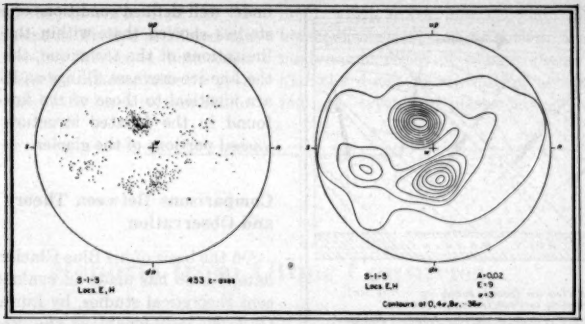

Fig. 8. *Combination of Five Fabric Diagrams of Coarse Bubbly Ice from Localities E and H. Pole of foliation plane is at w. Note strengthening of "near" maxima and weakening of "far" maxima, with almost complete loss of resolution of far maximum between w and n.*

though this feature was not found earlier in fabrics studied by Rigsby. This tendency toward greater density of the near maxima (those nearer to the pole of the foliation plane) is clearly shown in Figure 8, which is a composite of four fabric diagrams from location H and one from location E. It can be seen, moreover, that the far maximum between *w* and *n* is quite weak. This may result from local variations in the orientation of the pattern. Rigsby has recently suggested that three-maximum fabrics are more typical of multiple-maximum patterns than are the four-maximum fabrics. In the Blue Glacier samples, however, the four-maximum fabrics persist, though the fourth maximum is usually weak.

Interrelationships and Origins of Ice Fabrics

The relationship between fine ice and adjacent coarse bubbly ice suggests possible origins for both. The single-maximum fabric of fine ice is exactly what might be expected to result from mechanical plastic flow, in the form of simple shear across the foliation plane, promoted by translational gliding of the individual ice crystals along their basal planes. The multiple-maximum fabric of adjacent coarse bubbly ice, however, contains no crystals oriented favorably for basal glide. Hence, it does not seem likely that the latter fabric could result from simple mechanical plastic flow. Thus, the conclusion is suggested that in fine-ice layers, the ice has been deformed by mechanical plastic flow, and that subsequent recrystallization of the fine ice leads to the formation of coarse bubbly ice. The unfavorable orientation of the ice crystals in the coarse ice then prevents further rapid deformation by mechanical plastic flow.

This conclusion is supported by the observation that fine-ice layers are thicker and more abundant near the glacier margins, where the most active deformation takes place, than near the center, where deformation (near the surface) is slow. On the basis of both extensive field observations and laboratory experiments, Rigsby found that grain size decreases with increase of strain rate in active glaciers. In addition, the Soviet glaciologist, P. A. Shoumsky, has shown experimentally that crystal size is reduced within "shear zones" in ice specimens subjected to tangential stresses. Moreover, the ice in these experimentally deformed shear zones is similar both in texture and in *c*-axis fabric to the fine ice in Blue Glacier.

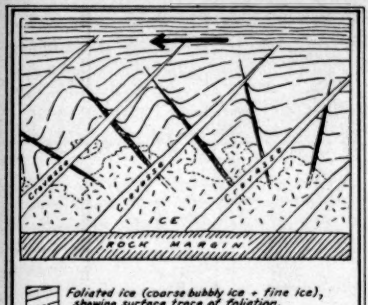
CREVASSE
CREVASSE
CREVASSE
ICE
ROCK MARGIN
Foliated ice (coarse bubbly ice + fine ice), showing surface trace of foliation.
Filled crevasse, showing foliation developed in the fine-ice filling
Coarse clear ice, in which the pre-existing foliation has been obliterated by recrystallization.

Fig. 9. *Schematic Plan Diagram (seen from above) of Marginal Portion of Glacier Near Locality K. Arrow shows direction of ice movement; open crevasses are labeled; foliation dips nearly vertically. Crevassed zone about 300 feet wide.*

It is also considered possible, and supported by field observations, that some fine-ice layers originate as snow fillings in crevasses instead of as a direct result of the flow process of the glacier. Figure 9 shows the geometry of such crevasse fillings. The fillings occur only in the outer part of crevasse zones along the glacier margins. The foliation pattern in these zones has been greatly disrupted by faulting and folding, and the ice is predominantly of the coarse, clear type characteristic of stagnant or near-stagnant zones at the glacier margins. The closed crevasses containing the fine-ice fillings have been rotated 90° or more from their original trend, and a few have been rotated to positions nearly parallel to the glacier margin.

The small number of crevasse fillings and the large amount of fine ice (about 20% by volume) in the actively deforming areas inward from the margins make it clear that such fillings do not account for the bulk of fine ice in the glacier. However, the crevasse fillings provide an opportunity to study *c*-axis fabrics produced naturally under well-defined conditions of stress. Such studies showed that, within the statistical limitations of the technique, the fabrics of the fine-ice crevasse fillings on Blue Glacier are identical to those of the fine-ice layers found in the foliated structure of uncrevassed portions of the glacier.

Comparisons Between Theory and Observation

On the basis of his Blue Glacier ice-fabric data, Kamb has made an evaluation of recent theoretical studies, by himself and by G. J. F. MacDonald, of the recrystallization process. Assuming that the recrystallized fabric develops, from an initial fabric similar to that of fine ice, through growth of the more favorably oriented crystals at the expense of the less favorably oriented ones, Kamb's computations indicate that a recrystallization fabric can be predicted with maxima in about the same positions as the far maxima of observed four-maximum fabrics. In the case of uniaxial compression or tension, Kamb's theory suggests that the *c*-axes of recrystallized ice should tend to cluster about the unique stress axis regardless of whether it is compressional or tensional.

The results of MacDonald's calculations differ markedly from those of Kamb. MacDonald's theory predicts that, at reasonably low pressures, a preferred orientation will occur in course-ice fabrics at the pole of the foliation plane. In addition, MacDonald's theory predicts that, under uniaxial compression or tension, a circular pattern of *c*-axes inclined about 55° to the unique stress axis will occur.

Kamb notes that both theories result in predicted patterns which differ in many respects from the actual multiple-maximum fabric patterns observed in course ice. Both theories assume conditions of homogeneous stress in the process that produces the multiple-maximum fabrics; Kamb feels that removal of this assumption may bring the predictions of the two theories closer

together. He notes, however, that the degree of disagreement between predicted and observed coarse-ice fabrics in both cases makes both theories unacceptable in their present form, and calls for a further refinement which takes into account the non-homogeneous stress distribution; the thermodynamic effect of plastic strain work; and the direct re-orientation accompanying intra-crystalline plastic flow.

Reports from Other Countries

The following are brief notes on reports of results obtained in the IGY programs of other countries. The first two reports appeared in Nature, *September 12, 1959, and the third was published in* The Geophysical Journal, *December, 1959.*

Radio-Noise Outbursts and Occurrence of Solar Flares

A report by L. D. de Feiter, A. D. Fokker, and J. Roosen, of the Ionosphere and Radio Astronomy Section, Netherlands Postal and Telecommunications Services, The Hague, sheds light on two questions concerning solar flares and their terrestrial effects: (i) Why are some flares accompanied by radio-noise outbursts and not others? (Past observations have shown that radio-noise outbursts very frequently accompany outstanding flares but rarely accompany minor flares.) (ii) How can flares be distinguished from similar events which are not flares?

Using the nearly complete IGY flare-patrol coverage listed in the *Quarterly Bulletin on Solar Activity* of the Meudon Observatory, France, and solar radio-noise data at 200, 545, and 3000 mc/sec from the Nera (Holland), Paramaribo (Surinam), Hollandia (New Guinea), Ottawa (Canada), Tokyo (Japan), and Berlin (Germany) observatories, the investigators correlated flare events with solar radio-noise events that occurred during the IGY period. It was found that for flares of importance 1 (the lowest class of flare importance) those that were "impulsive" in nature—starting suddenly and reaching maximum development about 5 minutes later, on the average—were accompanied by noise outbursts about 10% more frequently than those that were non-impulsive, and about 17% more frequently than all flares of this class. For impulsive and non-impulsive flares of importances 2 and 3, however, no difference was found in frequency of associated radio-noise outbursts.

These findings lead the investigators to believe that, in the case of importance-1 flares at least, impulsiveness may bear on the question of why some flares appear to cause noise outbursts while others do not. They also point out that the radio evidence tends to support the conclusion of an International Astronomical Union working group on flare classification, in 1955, that suddenness of commencement is one of the main criteria for distinguishing flares from similar solar phenomena.

Radio Noise and the Heliographic Distribution of Related Solar Flares

L. R. McNarry, of Upper Air Research, National Research Council, Ottawa, Canada, reports on correlations of radio-noise bursts at 48 mc/sec with the distribution of flares on the solar disk for the periods June 20–July 31, 1957, September 1–Octo-

ber 1, 1957, and June 1–July 31, 1958. The noise-burst data were taken from auroral-radar film records from the Resolute station (75°N, 95°W), of the Canadian IGY auroral radar chain.

Results of these correlations showed a great preponderance of flares in the northern hemisphere of the sun during the three periods of investigation. In addition, a definite peak in flares associated with radio noise occurred near the central meridian, and more such flares occurred in the sun's northwest quadrant than in any other. The author interprets these results as an indication that ". . . present conditions in the solar corona favour the emission of radio noise at very high frequencies from flares occurring in the north-west quadrant of the solar disk."

Wind Velocity and Microseisms in the Antarctic

A research note by J. MacDowall of the Royal Society presents the results of a study of microseisms recorded at the Royal Society Base, Halley Bay, Antarctica, from December 25, 1957, to May 10, 1958. The Royal Society Base was situated near the seaward edge of an ice shelf on the eastern side of the Weddell Sea. Although mostly afloat, the shelf was grounded in a few places near the ice front. Microseisms with periods of about one second predominated, and only these are discussed in the report. However, periods of one-half second were observed at times of intense activity, and on a few occasions 15- to 30-second periods were recorded. These longer-period microseisms lagged behind the onset of those of shorter period by 15 hours or more.

A close association was noted between wind velocity and microseism amplitude from late December to late February, during the austral summer, when most microseismic activity occurred at the base. Microseismic activity was also considerably affected by wind direction, increasing noticeably when winds were on-shore. Activity fell off rapidly near the end of February, and for the remainder of the year microseisms were active only during prolonged spells of very strong winds. On the basis of these observations, the author concludes that ". . . the microseisms originated at the ice-front and that the cover of sea-ice . . . for three-quarters of the year . . . stifled microseismic activity."

IGY Bibliographic Notes

This is the twentieth of a series of bibliographic notes on IGY and IGC-1959 programs and findings. The references are selected largely from a bibliography under preparation in the Science and Technology Division of the Library of Congress. (An interim IGY bibliography, covering the period January 1951–August 1958, prepared by the Library and published by the Academy with support of the National Science Foundation, is available from the Academy, 2101 Constitution Avenue, N.W., Washington 25, D. C., for $1.00. The 64-page volume contains 704 references.)

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NATIONAL ACADEMY OF SCIENCES

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IGY BULLETIN

A monthly survey of programs and findings of the International Geophysical Year and the International Geophysical Cooperation-1959 as related primarily to United States programs.

Cosmic Rays from Solar Flares

The following report is based on a paper presented by J. R. Winckler, of the University of Minnesota Department of Physics, at the Symposium on Upper Atmosphere Solar Relations, held during the December 28, 1959, meeting of the American Association for the Advancement of Science, Chicago, Illinois.

In considering the nature and source of primary cosmic rays, the question frequently arises as to whether the sun, as a typical star, is a source of cosmic radiation. It is known that the sun sporadically emits bursts of high-energy cosmic rays, since five such bursts were detected by sea-level monitoring instruments during the past 15 years. The most recent was observed as a great increase in cosmic-ray intensity on February 23, 1956. On the basis of these five events, it was widely believed prior to the IGY that the sun seems to emit either large bursts of cosmic rays or none at all.

During the IGY and IGC-59 period, however, improved techniques for studying cosmic rays at high altitudes have resulted in approximately 25 additional observations of intense cosmic-ray emission from the sun. Though similar in nature to the cosmic rays detected in the five sea-level cases, those observed at high altitudes have lower average energies and therefore do not penetrate deep enough into the atmosphere to be detectible by the world-wide network of sea-level monitors. These observations of solar cosmic rays at high altitudes have added greatly to an understanding of the process by which solar cosmic rays are accelerated, of their propagation through space, and of their interactions with the earth's magnetic field and upper atmosphere. (See *Bulletins 3, 4, 8, 10, 11, 15, 25,* and *31* for additional information on the IGY and IGC-59 cosmic-ray programs and results. *Bulletin No. 25* contains a relatively detailed report on one of the high-altitude solar-cosmic-ray events not described in the present report.)

Observations of these high-altitude

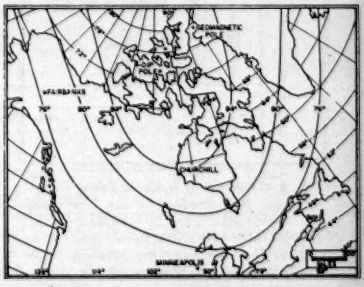

Fig. 1. *Locations of Balloon Launching Sites Relative to Geomagnetic Latitude.*

events during the IGY and IGC-59 fall into three categories: i) direct measurements of cosmic-ray particles with balloon-borne equipment (Figs. 1 and 2); ii) direct measurements with satellites; and iii) measurements of increases in ionospheric electron density over the earth's "polar cap," caused by collisions of cosmic rays with atmospheric particles. This report is concerned primarily with results of the balloon observations, but associated ionospheric effects and satellite measurements are also mentioned where appropriate. All 25 events were detected by means of their ionospheric effects, 11 were also observed by balloon flights, and four also by satellites.

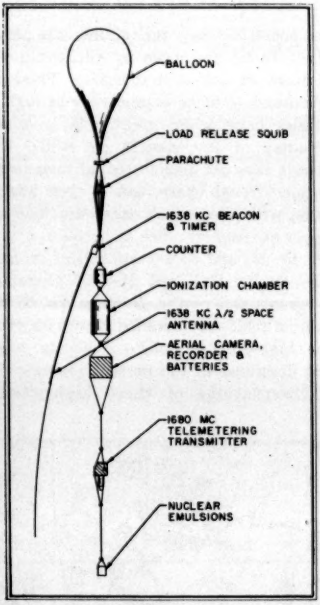

Fig. 2. *Cosmic-Ray Balloon Train Developed for IGY Studies by the University of Minnesota. The ¾-millimeter-thick, 180,000-cubic-foot polyethylene balloon, as well as the parachute, are actually much larger than shown relative to the instrumentation.*

The Balloon Program

The over-all IGY and IGC-59 balloon program of cosmic-ray measurements at high altitudes included approximately 100 flights conducted by the University of Minnesota, 20 to 25 flights by the University of Iowa, and a considerable number by University of Chicago and University of California groups. The flights were made at several different latitudes: launching sites included Fairbanks, Alaska; Fort Churchill, Canada; Minneapolis; Chicago; and other locations.

A standard balloon "train" (see Fig. 2) was developed for the IGY program by the University of Minnesota. University of Iowa balloon experiments were similar in many respects. Instruments in the University of Minnesota train consist basically of an integrating ionization chamber, a single Geiger counter, and a package of nuclear emulsions. The ionization chamber and Geiger counter are essentially omni-directional in response, and both give a continuous recording of the radiation intensity. By comparing their readings it is frequently possible to evaluate the mean ionization and the energies of the particles and to obtain information about their nature and variations with time. The nuclear emulsions permit evaluation of the types of particles and the energy spectrum.

Solar-Cosmic-Ray Outbursts

In order to examine the characteristics of these solar-cosmic-ray events, three particularly good examples have been selected. All three events were detected both by their ionospheric effects and by balloon measurements, and one was also detected by a US-IGY satellite.

Event of August 22, 1958: This solar cosmic-ray event was especially well ob-

served by balloons, satellites, and ionospheric detectors. Figure 1 shows the locations of the balloon observations with respect to the high geomagnetic and geographic latitudes over North America. Balloon experiments were conducted during the event at Fort Churchill, Canada, by K. A. Anderson of the University of Iowa; at Fairbanks, Alaska, by a University of Minnesota group in cooperation with the University of Alaska; and at Minneapolis, also by the University of Minnesota.

Figure 3 summarizes the principal flight results from Fort Churchill, Fairbanks, and Minneapolis, and from the sea-level neutron monitor at Deep River, Ontario, Canada. The Fort Churchill balloon, launched at about 1200 UT, August 22, was floating at high altitude at the time of occurrence of a Class 3+ flare in the sun's chromosphere, about two hours later. (Class 3+ is the highest category in the flare-importance classification system, based on solar-disk area covered by flares.) Within an hour, the balloon's instruments showed large counting-rate increases, which reached a peak about 20 times the normal cosmic-ray intensity. The great burst of cosmic rays decreased after about four hours and then declined smoothly, but two days later the radiation intensity observed was still slightly higher than the normal cosmic-ray background intensity. It appears from the flight data that particle incidence in these events is very irregular during the first four hours, with minima and maxima occurring in a random manner, followed by a smooth fading away.

A flight was also in the air at Minneapolis at the time of the flare, but it observed no similar effects. This clearly shows that the phenomenon resulted from the arrival

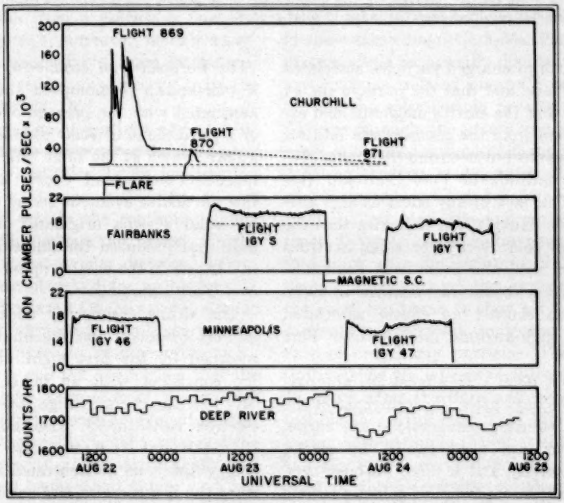

Fig. 3. *Summary of Principal Flight Results from Fort Churchill, Fairbanks, and Minneapolis, and Data from the Sea-Level Neutron Monitor at Deep River, Canada, for the August 1958 Event. (Deep River data courtesy of Hugh Carmichael.) Dashed horizontal lines represent approximate level of normal background cosmic-ray intensity.*

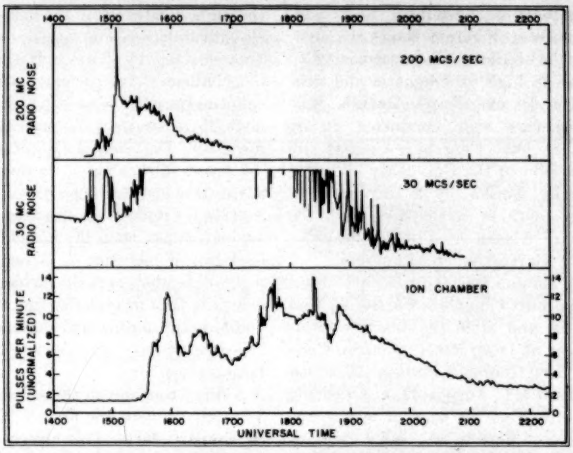

Fig. 4. Comparison of Ion Chamber Data at High Altitude with Solar Radio Noise Data for the August 1958 Event. The 30-megacycle profile shows sequence from normal cosmic-noise level to noise bursts, followed by the long-lasting noise storm, and finally, the attenuation of cosmic noise resulting from the influx of solar protons.

at the earth of charged particles associated with the flare, and that the particle energy was such that the earth's magnetic field excluded them from the geomagnetic latitude of Minneapolis but not from the higher geomagnetic latitude of Fort Churchill (see Fig. 2). This lack of any effect at high altitude above Minneapolis indicates that the number of solar γ-rays or solar neutrons associated with the event was negligible. The sea-level cosmic-ray monitor at Deep River also showed no effects associated with the high-altitude increase over Fort Churchill.

At about 0330 UT, August 24, approximately 1½ days after the occurrence of the flare, an intense geomagnetic storm began. The storm was accompanied by strong auroral activity and a large Forbush-type decrease in the intensity of galactic cosmic rays, as shown by the sea-level monitor and by balloon flights at Fairbanks and Minneapolis (see Fig. 3, IGY T and IGY 47). (The Forbush-type cosmic-ray decrease is a well-known phenomenon thought to be associated with the passage over the earth of a great cloud of solar plasma ejected by a flare, which at the same time generates a magnetic storm and causes auroras.) In this particular event, it seems certain that the solar plasma originated in the same flare that produced the immediate cosmic-ray effects in the earth's upper atmosphere over Fort Churchill.

The strong cosmic-ray effects observed at Fort Churchill and the smaller increase recorded by the first flight at Fairbanks are consistent with an influx of protons (H^+) in the energy range 100–400 million electron volts (mev). Also, both the Fort Churchill and Fairbanks data indicate an energy spectrum concentrated strongly toward the low energies and having very few high-energy particles. Although the lower energy limit detectible by the balloon instrumentation was 100 mev, measurements

by IGY satellite 1958 Epsilon (Explorer IV), which was making continuous passes over the northern United States at the time of the event, extend the lower limit downward to energies as low as 30 mev.

An important correlation was also made between the cosmic rays observed at the earth following the August 22 flare and the intense solar-radio-noise bursts observed during the flare (see Fig. 4). The radio emission from this flare was of the continuum-outburst type, or Type IV in the spectral classification system for solar radio emission (see *Bulletin No. 29*). It is believed that this type of solar radio spectrum is emitted by synchrotron-type radiation produced in a flare region. It seems probable that the acceleration of high-energy particles on the sun is closely associated with these same magnetic regions and that there is essentially a 1–to–1 correlation between the cosmic-ray particles and the Type IV radio emission from a particular flare. As shown in Figure 4, moreover, there is a suggestion of a similarity of form in the cosmic-ray and radio-noise records from the flare of August 22, 1958.

The observation of particles at high altitudes more than a day after the flare indicates that, in addition to an acceleration mechanism, a storage mechanism is also necessary to explain the continuing influx of particles throughout this period. (In the still more intense events discussed below, particles were observed for as long as 11 days after the flare.) Of the several storage mechanisms suggested, the experimental facts are best fitted by storage in the vicinity of the sun and the assumption that the stored particles escape from the storage region, by diffusion or an equivalent mechanism, until the supply is exhausted and the intensity observed at the earth again falls to the normal background value.

The decrease in galactic cosmic rays at the time of the geomagnetic storm has previously been explained by other investigators in terms of a mechanism in which

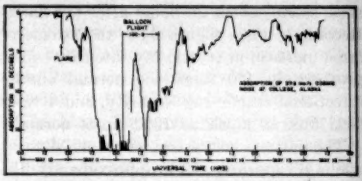

Fig. 5. *Absorption of Galactic Radio Noise During the May 1959 Event, Indicating Bombardment of the Polar Cap by Solar Cosmic Rays. (Courtesy of Leinbach and Reid.) Flight IGC–8 was conducted by the University of Minnesota group at Minneapolis.*

the galactic particles are diverted away from the earth by magnetic fields associated with the plasma cloud blown out from the flare. However, since the solar cosmic rays begin to reach the earth almost immediately following the flare, whereas the cloud arrives a day or two later, it is evident that the particles cannot be trapped in these same magnetic fields. Possibly the plasma cloud is actually highly turbulent and contains isolated magnetic fields, permitting the solar cosmic rays to penetrate directly through the cloud and reach the earth with only a time-of-flight delay.

Event of May 11–12, 1959: This event also began with a Class 3+ flare—at about 2000 UT on May 10—and extremely intense Type IV solar radio noise. Within four hours after the beginning of the visible flare, the D-layer of the ionosphere over the polar cap began to show an increase of radio-wave absorption, indicating the presence of cosmic-ray particles. The absorption reached its maximum intensity about 12 hours after the flare and was still detectible five days later (see Fig. 5). Following notification of the onset of the polar-cap absorption, by H. Leinbach and G. C. Reid of the University of Alaska's Geophysical Institute, the University of Minnesota group conducted a series of balloon flights at Minneapolis; the series began after the sudden commencement of the geomag-

netic storm, about 26 hours after the flare. Records of these flights show an extremely large increase in cosmic-ray intensity—approximately 150 times the normal omnidirectional cosmic-ray intensity, and a vertical flux as much as 1000 times normal.

The particle increase observed at Minneapolis disappeared after approximately 12 hours, during which there were many fluctuations and a close association with the geomagnetic storm at that latitude. Although the event appears to differ from that of August 22, 1958, in this respect, the University of Minnesota investigators believe it to be actually of the same character. They believe that the unusual presence of particles during the geomagnetic storm was associated with the very high intensity of the event combined with a severe perturbation of the earth's magnetic field, permitting particles to enter at normally forbidden latitudes. (High-energy cosmic rays can penetrate the geomagnetic field at all latitudes; lower-energy particles are diverted by the magnetic field and can penetrate only at higher geomagnetic latitudes, the latitude "cutoffs" for different particles depending on their energies.)

The polar-cap ionosphere records indicate a continuous and long-lasting bombardment by these particles at high latitudes before, during, and after the transitory increase observed at Minneapolis in correlation with the geomagnetic storm. As usual in these events, a Forbush decrease in the sea-level intensity of galactic cosmic rays was observed. Hence, it is clear that in this event, also, the solar cosmic rays could not have been trapped in the plasma cloud from the flare, but came directly from the flare with a transit time of 4–12 hours and continued to impinge on the earth during the Forbush decrease.

An analysis of the nuclear emulsions carried in this series of flights, the first to provide good exposures of solar cosmic rays, was made by E. P. Ney and P. S. Freier of the University of Minnesota. The analysis shows that the particle spectrum, like that in the May 1958 event, was very steep and that the particles consisted almost entirely of protons. Detailed studies by Ney and Freier of emulsions from other flights have also shown the presence of electrons and alpha-particles at certain times during these strong geophysical events. Although in much smaller numbers than the protons, these electrons and alpha particles occur in excess of their numbers in the normal cosmic-ray flux.

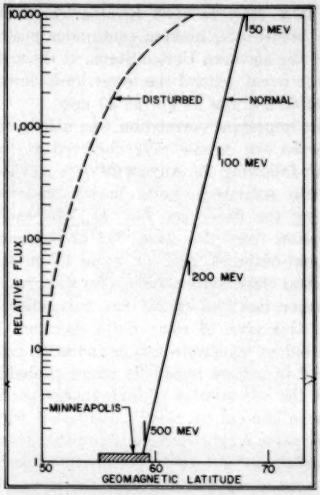

Fig. 6. *Estimate of Latitude Effect in the Vicinity of Minneapolis.*

It has previously been found that, in strong auroras at latitudes below the auroral zone (the high-latitude band along which auroras are most intense and most frequent), there is a close correlation between the presence of auroral X-rays and visual luminosity. Scintillator records for the Minneapolis flights during the May 1959 event show high counting rates at the time of maximum auroral activity accompanying the geomagnetic storm. The count-

ing rate reached its highest peak, 8000 counts/sec, at about 0830 UT on May 12. At exactly this time, the visual aurora was intense at the zenith over Minneapolis. In addition, detailed study of all-sky camera records from the stations at Choteau, Montana, Fargo, North Dakota, and Williams Bay, Wisconsin, shows that the aurora reached the zenith at the latitude of Minneapolis within a few minutes' time during the intense bursts of auroral X-rays.

The University of Minnesota investigators assume that the presence of low-energy solar cosmic rays at Minneapolis during the geomagnetic storm is evidence for a complete change of the Störmer cutoffs (the latitude cutoffs) of the earth's dipole magnetic field. Figure 6 shows graphically an estimate of this effect, which permits the entry of low-energy particles at lower-than-normal geomagnetic latitudes. Although the effect is not understood in detail, the University of Minnesota workers suggest a simple mechanism that may account for it: in the far reaches of the earth's magnetic field, the lines of force may break off and connect directly with a portion of the solar magnetic field carried outward by the plasma from the flare.

The May 1959 event was also observed by counters carried in Soviet meterological balloons at geomagnetic latitude 64° N. The shape of the spectrum deduced from their measurements is very similar to that obtained by the variety of instruments used at Minneapolis, and also closely resembles the spectrum of the August 1958 event.

Series of events of July 1959: In July 1959 a series of three great cosmic-ray flares occurred. The first began with a strong flare early on July 10, the second with a flare on July 14, and third followed a flare on July 16 (see Fig. 7). The three outbursts, covering virtually the entire period from July 10 to 18, were all presumably caused by solar protons having very steep energy spectra, as were the first two

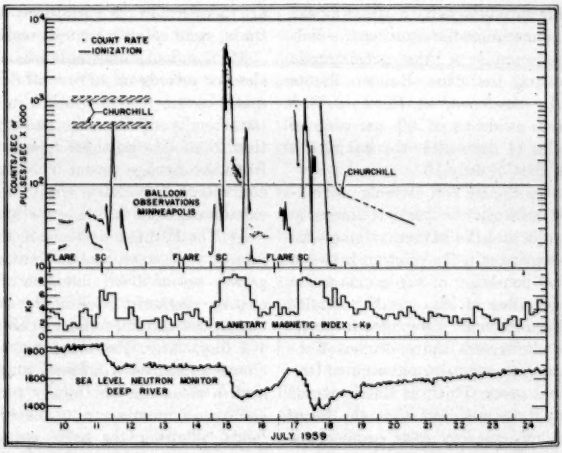

Fig. 7. *Correlation of Minneapolis and Fort Churchill Balloon Data with Planetary Magnetic Indices and Sea-Level Neutron-Monitor Data for the Three Events of July 1959.*

events described, and were therefore not detectible by sea-level instruments.

In all cases, the high-altitude observations over Minneapolis showed a strong correlation with geomagnetic activity, a condition that seems necessary to permit the normally forbidden lower-energy particles to penetrate to balloon altitudes at that geomagnetic latitude. Polar-cap ionospheric effects appear to have been intense and continuous throughout the period. Balloon flights conducted at Fort Churchill by James Earl, of the University of Minnesota, made direct observations, with nuclear emulsions and instruments, of the solar protons at high latitude during these events.

Although the first of the three July 1959 events ended at Minneapolis on July 12, two days after onset, it persisted at higher geomagnetic latitudes for many days, overlapping the flare of the 14th. This second cosmic-ray flare of the July 1959 series resulted in the highest intensity of solar cosmic rays observed by the University of Minnesota group. They estimate that an intensity possibly 10,000 times that of the normal background intensity may have been reached in space immediately after the sudden commencement of the geomagnetic storm following the flare. Balloon flights conducted by Anderson at Resolute Bay showed direct evidence of the presence of solar particles 11 days after the last of the three flares, that of July 16.

As shown in Figure 7, a striking correlation existed between the particle intensity at Minneapolis and the planetary magnetic indices, showing again the relation between the disturbed condition of the geomagnetic field and the influx of low-energy particles at lower-than-normal geomagnetic latitudes. Also shown are the enormous Forbush decreases accompanying each of the geomagnetic storms. Thus, in this series of events also, it is apparent that the large increases in lower-energy solar cosmic-rays at high altitude must arise from a different mechanism than that causing the decreases in high-energy galactic cosmic rays at sea level.

Conclusions

Prior to the IGY, very-high-energy galactic cosmic rays and occasional bursts of high-energy solar cosmic rays, were detected by sea-level monitoring instruments. IGY and IGC-59 balloon studies have since shown that intense bursts of lower-energy cosmic rays, detectible only at high altitudes where they are subjected to less screening by the atmosphere, are also frequently associated with great solar flares. Analysis of three such events observed during the IGY and IGC-59, by balloons, satellites, and ionospheric-absorption recorders, permits the following conclusions and speculations:

1) A close correlation exists between the Type IV (continuum outburst) solar radio noise emitted by synchrotron-type radiation produced in flare regions and the cosmic-ray particles from the same flare region. Hence, it is likely that the particles are accelerated to cosmic-ray energies in these same solar magnetic regions.

2) The continuing influx of these particles for periods up to several days requires a storage mechanism; such a mechanism in the vicinity of the sun, and the assumption that the particles escape gradually from the storage region by diffusion or an equivalent mechanism until the supply is exhausted, best fits the experimental data.

3) The Forbush decrease in the sea-level intensity of cosmic rays coming from the galaxy results from diversion of the particles by magnetic fields in the solar plasma ejected by the flare and reaching the earth 1–2 days later. However, instead of being characterized by a uniform magnetic field, such a cloud may be highly turbulent and contain a number of isolated magnetic fields, allowing the solar cosmic rays to move directly through the cloud and reach the earth with only a time-of-flight delay.

Thus, the intensity of the lower-energy solar cosmic rays may remain high, or even increase, when the plasma cloud reaches the earth, while the intensity of the high-energy galactic cosmic rays falls off greatly.

4) Perturbation of the earth's magnetic field by the solar plasma cloud following a flare permits low-energy particles to penetrate the magnetic field at lower geomagnetic latitudes than normal. A simple mechanism suggested to explain this phenomenon is that the lines of force of the earth's magnetic field may break off in the far reaches of the field and connect with portions of the solar magnetic field carried in the plasma cloud.

United States Meteorological Satellite

At 6:40 am, April 1, 1960, the United States launched from Cape Canaveral, Florida, the Tiros I meteorological satellite. It entered a nearly circular orbit about 12 minutes later. The satellite, designated 1960 Beta 2, carries two small television cameras to take still photographs of the earth's cloud cover for transmission to receiving stations and subsequent use in meteorological research and analysis.

In accordance with customary procedures, orbital and instrumental details were sent immediately to the Committee on Space Research (COSPAR), in The Hague, for transmission to all COSPAR participants. Data acquired by the satellite will be deposited in the World Data Centers established during the IGY, and will also be forwarded to COSPAR. Thus, the data will be made available to the world scientific community.

Over-all responsibility for the Tiros project rests with the National Aeronautics and Space Administration. NASA's Goddard Space Flight Center, which directs the project, prepares the command programming relayed by the ground stations to the satellite. The programs are based on information from the NASA Computing Center and the Meteorological Satellite Section of the US Weather Bureau. Many other private and public agencies participated in the numerous phases of preparation of the satellite instrumentation, command and tracking facilities, and launching.

Satellite Characteristics

1960 Beta 2 is shaped roughly like a large hatbox (see Fig. 8), 42 inches in diameter and 19 inches high. The satellite weighs 270 pounds and its top and sides are covered almost completely with banks of solar cells —some 9200 in all—which supply power for the experimental equipment. A single command receiving antenna extends perpendicularly outward from the top of the satellite, and four two-frequency transmitting antennas, 90° apart, extend diagonally outward from the bottom.

Wound around the outside of the satellite was a de-spin mechanism consisting of two weights attached to cables. About 10 minutes after payload separation from the third-stage rocket the weights unwound, slowing the satellite from its initial spin rate of about 136 revolutions per minute to 10 rpm, a rate at which unblurred pictures can be taken. Since interaction of the satellite's metal components with the earth's magnetic field tends to slow the spin further, two pairs of tiny rockets are located around the base plate to "spin up" the satellite again, on command, when the rate falls to 9 rpm, the minimum rate desired.

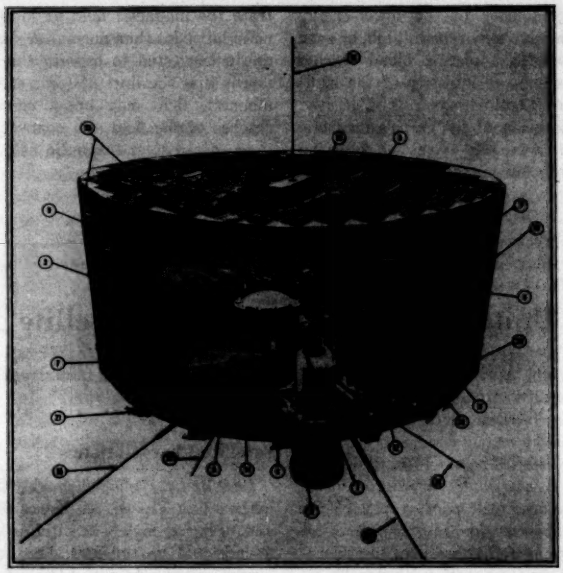

Fig. 8. *Cutaway View of 1960 Beta 2 (Tiros I). Key: 1) Vidicon television camera; 2) wide-angle lens; 3) tape recorder; 4) electronic timer for programming; 5) television transmitter; 6) chemical batteries; 7) camera electronics; 8) tape-recorder electronics; 9) control circuits; 10) auxiliary controls; 11) power converter for tape motor; 12) voltage regulator; 13) battery charging regulator; 14) auxiliary synchronizing generator for television camera; 15) transmitting antennas; 16) receiving antenna; 17) solar sensor; 18) solar cells; 20) de-spin mechanism; 21) spin-up rockets.*

Launching Vehicle

1960 Beta 2 was boosted into orbit by a three-stage Thor-Able rocket similar to those used to launch satellite 1959 Delta (Explorer VI) and space probes Pioneer I and 1960 Alpha (Pioneer V). (*Bulletin No. 18* describes briefly the vehicle used to launch Pioneer I.) The Air Force Ballistic Missile Division had primary responsibility for development of the launching vehicle, for mating booster and payload, and for the launch.

The 1960 Beta 2 launching vehicle differed from previous Thor-Able vehicles in two respects: (1) For the first time in any NASA satellite launch, a tracking beacon was carried in the third-stage rocket, which remains in orbit with the probe. The third-stage rocket has been designated 1959 Beta 1. (2) Before its ignition, the third-stage was allowed to coast for about 6½ minutes after separation from the second stage. During this interval, the third stage and the payload were spin stabilized.

Orbital Characteristics

At present, 1960 Beta 2 is approximately 433 statute miles above the earth's surface

at perigee and 465 miles high at apogee. Since a circular orbit at a distance of about 460 statute miles was intended, the orbit achieved, with an eccentricity (or deviation from a true circle) of only .003, is considered nearly perfect. The orbit is inclined at an angle of 48° to the equator, and the satellite's orbital period is approximately 99 minutes (see Fig. 9).

Burn-out velocity of the third stage was 16,812 miles per hour, slightly higher than the intended velocity. Because of its highly stable circular orbit, 1960 Beta 2 is expected to have a lifetime of some tens of years. Based on the estimated lifetime of the electronic equipment, however, the experiments are expected to cease functioning about three months from the date of launch.

Experiment and Instrumentation

The Tiros instrumentation and the special ground-station equipment required for the experiment were designed and constructed by the Astro-Electronic Products Division of RCA, under technical direction of the Goddard Space Flight Center and supervision of the US Army Signal Research and Development Laboratory. The Meteorological Satellite Section of the US Weather Bureau, assisted by military and private agencies, has primary responsibility for analysis and interpretation of the cloud-cover data gathered by the satellite.

An ultimate goal of the weather forecaster is to have synoptic world-wide meteorological observations available at all times. Present observing networks cover about one-fifth of the total atmospheric mass, leaving large oceanic areas, desert and polar regions, and other remote portions of the globe completely devoid of weather observing stations. Storms may reside in such areas for days without detection.

Pictures such as those obtained by 1960 Beta 2 show cloud patterns indicating the birth, or subsequent stages of development, of hurricanes, cyclones, and other kinds of weather activity in areas far from normal observation stations. Ultimately, such photographs, plus other meteorological information obtainable only by satellites, may greatly improve our understanding of the causes and patterns of weather and our ability to forecast. Perhaps some theories relating to weather control may also result.

The major instrumentation in 1960 Beta 2 consists of two television cameras approximately the size of a water glass. Except for lens equipment, the cameras are identical, consisting essentially of a ½-inch Vidi-

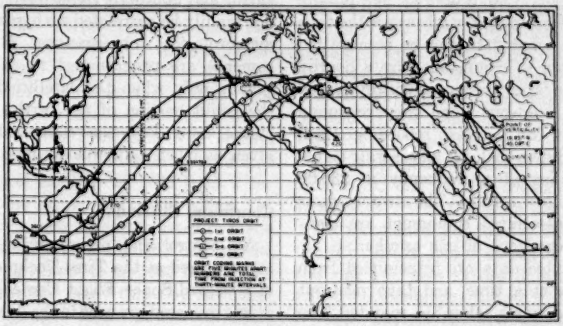

Fig. 9. *Earth Trace of First Four Orbits of 1960 Beta 2.*

con tube and a focal-plane shutter that permits storage of still pictures on the tube screen. An electron beam converts the stored pictures into television-type electronic signals, which are transmitted to ground receivers on command.

One camera has a wide-angle, f/1.5 lens of relatively low resolution; this camera is capable of covering an area of the earth's surface (from an altitude of about 460 statute miles) roughly 700 to 800 miles square. The pictures overlap, thus providing continuous coverage during the operating periods of the cameras. The second camera, which has a narrow-angle, relatively high-resolution, f/1.8 lens, covers an area approximately 80 miles on a side in about the center of that covered by the wide-angle camera. The wide-angle camera, with a resolution of about 1½ miles, is designed to provide pictures of broad cloud-cover patterns (see Fig. 10), while the narrow-angle camera, with a resolution of a little more than 1/10 mile, shows specific cloud types in greater detail. Both cameras have shutter speeds of 1.5 milliseconds and video bandwidths of 62.5 kilocycles; both take 1/2 frame per second, and each frame has 500 lines.

Magnetic tape recorders connected to each camera can store up to 32 photographs each for later relay on command from a ground station. Also, if desired, new picture data from the cameras can by-pass the tape containing stored data and be transmitted directly when so commanded by a nearby station. The tapes are automatically erased with each "read-out," and then re-wound immediately for the next recording. Each television system includes a two-watt transmitter sending at a frequency of 235.00 megacycles per second. The two systems and their associated equipment are completely independent of one another.

Photographic data are transmitted from one camera at a time, and tape read-out from both cameras takes 3½ minutes. The satellite is within transmission range of a ground station for as much as 12 minutes, and can send up to four minutes of photographic data collected while within range of the station. Immediately after being received at a ground station, the pictures are displayed on kinescopes for viewing and photographing. All original data are stored at NASA's Goddard Space Flight Center.

In order to identify the photographs geographically, the satellite's orbit is accurately computed by tracking reports. In addition, nine solar sensors on the satellite provide directional orientation by measuring the position of the satellite with respect to the sun. This information is transmitted to the ground station along with the photographic data; processing by computer then shows the north direction for each picture. An infra-red detector within the payload senses the crossing of the earth's horizon by the detector's line of sight, making it possible, in principal, to determine the attitude in space of the satellite's spin axis. However, the operation of this circuit has been erratic, and attitude data are slowly being obtained by photogrammetric analysis of known landmarks visible in the pictures.

Since 1960 Beta 2 is spinning on its axis, it cannot "look" at the earth at all times. Moreover, pictures cannot be taken when the satellite is over the night side of the earth, and Southern Hemisphere data cannot readily be correlated with ground-based meteorological observations. Hence, the cameras are programmed to take photographs only when the satellite is viewing the sunlit portion of the earth's Northern Hemisphere. Program commands can be given as much as five hours in advance.

Command Stations

All control and programming functions are prepared at the Tiros Technical Center of Goddard Space Flight Center. The programs prepared are sent to the data-acquisition stations for relay to the satellite. These

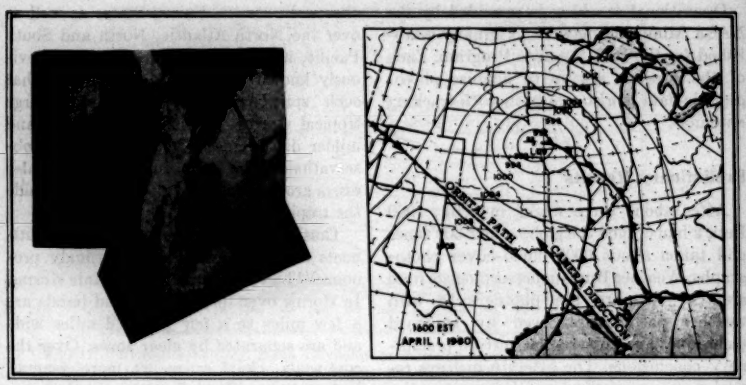

Fig. 10. *1960 Beta 2 Photograph of Storm Centered Over Nebraska on April 1, 1960, and Appropriate Surface Weather Map of Same Area. Circular cloud mass in upper part of picture is storm center; prominent cold front trails south and southwest from storm; large cloud mass in foreground was located near Gulf Coast. Photograph taken on satellite's fifth orbit, from height of about 450 miles over geographic position marked by "X".*

stations are under the direction of Goddard Space Flight Center.

There are two primary ground stations in the Tiros experiment. One, at Fort Monmouth, New Jersey, is operated by the US Army Signal Corps; the other, at Kaena Point, Hawaii, is operated by the Lockheed Missile and Space Division under contract to AFBMD and under technical supervision of the Signal Corps. Both stations can command the satellite and receive photographic data. Two "back-up" stations, which cannot command the satellite but which can receive data, are at Cape Canaveral, Florida, and Princeton, New Jersey.

The Fort Monmouth station programmed the television cameras of 1960 Beta 2 for the first time on April 1, 1960, about 1½ hours after launch, when the satellite made its first sweep over the East Coast of the United States. Since then, 1960 Beta 2 has been interrogated many times by both stations, producing a large number of unexpectedly useful photographs showing cloud patterns and broad geographic features on the earth's surface (Fig. 10).

Tracking

1960 Beta 2 carries two beacon transmitters for tracking purposes. The transmitters, operating on frequencies of 108.00 megacycles and 108.03 megacycles, both have a power output of 30 milliwatts. The signals of both transmitters can be modulated to provide information on satellite attitude, environmental conditions, and operation of the equipment carried by the satellite. To insure against failure of the entire experiment in case of damage to, or failure of, one of the transmitters, both frequencies carry the same data.

As mentioned previously, 1960 Beta 1, the third-stage rocket casing in orbit with the satellite, also carries a beacon transmitter for tracking purposes. This transmitter was battery-powered and lasted one day.

Operational tracking is provided by the NASA Minitrack network, originally established for the IGY Satellite Program. Each of the stations set up to acquire photographic data is also equipped with tracking antennas.

Preliminary Results

After about three weeks in orbit, 1960 Beta 2 had circled the globe about 300 times and taken about 6000 cloud-cover photographs. Weather Bureau meteorologists were able to compare the photographs with weather patterns observed by standard techniques and to arrive at certain preliminary conclusions. The satellite pictures reveal an unexpectedly large degree of organization in the cloud systems over much of the earth.

The most striking patterns found in the photographs are banded, inward-spiralling cloud formations associated with large storms, some as much as 1500 miles across, observed over the United States as well as over the North Atlantic, North and South Pacific, and Indian Oceans. It was previously known from radar observations that such spiral patterns characterize large tropical storms—hurricanes, typhoons, and milder disturbances. The 1960 Beta 2 observations show that such structure also exists around well-developed storms outside the tropics.

Thus far, the storms observed over continents have not exhibited as strongly pronounced banded structure as oceanic storms. In storms over the oceans, cloud bands are a few miles to a few hundred miles wide and are separated by clear zones. Over the continents, cloud areas are more general, with only poorly defined spaces between bands, or none at all. The spiral nature of the continental storms is indicated, however, by a characteristic wedge of cloudless air curving in toward the storm center behind a cold front, as shown in the Midwest storm of April 1 (Fig. 10).

Explosive Warming in the Antarctic Stratosphere

The following material is based on a paper given by Kirby J. Hanson, US Weather Bureau, at the Symposium on Antarctic Meteorology, Melbourne, Australia, February 1959. Mr. Hanson was Chief Meteorologist at the IGY Amundsen-Scott South Pole Station during the 1957–58 period.

With the establishment of IGY Amundsen-Scott South Pole Station, meteorologists were able to gain an insight into the annual temperature variations over the extremely cold south-polar snowfield and into the relationship of these variations to global temperature structure and atmospheric processes. This report describes one of many temperature processes from which evolves the annual stratospheric temperature pattern over the geographic South Pole.

Monthly Mean Stratospheric Temperature

The past few years' data reveal the properties of the annual variation of monthly mean stratospheric temperature with height over the geographic South Pole. These data show that, at a height of 19 kilometers (50-millibar constant-pressure level), the stratosphere cools for eight continuous months, ranging from −32°C in mid-November to −88°C in early August. With the return of direct solar radiation in spring, the stratosphere undergoes a four-month warming period (Fig. 11), a large portion of which is

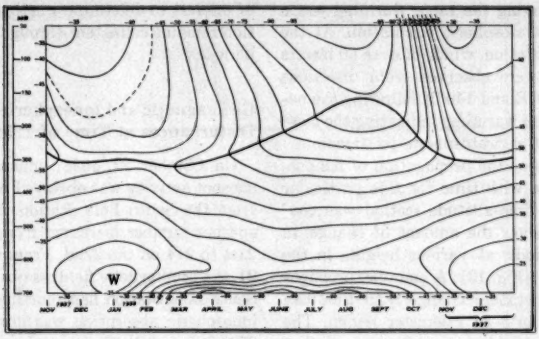

Fig. 11. *Variation of 30-Day Mean Temperature from the Surface (700-millibar level, on the South Polar Plateau) to an Altitude of 19 Kilometers (50 millibars) Over the IGY South Pole Station in late 1957 and Throughout 1958. Heavy line represents the mean tropopause.*

accomplished from mid-October to mid-November.

A surprising characteristic of the temperature regime of the south polar stratosphere is the abruptness with which it reverts from winter to summer temperature structure. This rapid transition was first pointed out by Harry Wexler of the Weather Bureau, who demonstrated it by the use of 10-day mean temperatures. He showed that, at the 50-millibar level over the South Pole Station in 1957, the temperature minimum was reached in mid-August and the maximum in late October and early November; this represents a total warming of 60°C (140°F) in less than three months, with 80% of it occurring during October. After early November, cooling begins at the 50-millibar level and continues through the summer solstice and into the winter night.

Explosive Warming in 1958

Because of the extreme temperature change observed in October 1957, high priority was given to the collection of high-altitude temperature data for October 1958 over the South Pole Station. During the long winter night, when stratospheric temperatures fell below —90°C, very little temperature data were obtained above a height of 15 kilometers because of premature balloon bursts. However, with the return of direct solar radiation in the spring, and with the use of special high-flying balloons, burst altitudes increased to 30 kilometers, and on two occasions exceeded 37 kilometers.

Daily soundings from October 12 to 29, 1958, were used to construct a time-altitude section (Fig. 12) showing the daily temperatures at various heights during this period of rapid temperature change. It is apparent from this section that the rapid stratospheric warming is not a steady day-to-day process, but consists of a number of short-period temperature changes. On October 22, after a week of small temperature undulations, the explosive phase of the warming began; it strengthened on the 23rd and reached a maximum rate on the 24th, when a tremendous 12-hour rise of 19°C occurred at the 15-millibar level (27 kilometers). Little or no temperature change was observed on October 25th; on the 26th and 27th, the stratosphere began to cool, only to undergo renewed warming on the 28th.

Accompanying the rapid warming was a change in stratospheric circulation. At the South Pole Station, winds of over 60 meters per second were observed from directions between 120°E and 140°E following the period of intense warming, indicating the close proximity of a stratospheric jet stream.

To determine the propagation of temperature change with time for this particular warming, a time-altitude section was constructed to show the amount of change, in 24-hour periods, at various heights in the stratosphere (Fig. 13). A complex propagation of temperature change with time can be seen in the 8–34 kilometer region. The maximum rate of warming occurred first near a height of 10 kilometers and rose in height with time; it next occurred at the highest observed level (34 kilometers) where it was decreasing in height with time; and it last occurred at 25–27 kilometers.

A surprising feature apparent in this section is that many of the properties associated with warming are also noted in the cooling that followed:—i.e., the propagation of temperature decrease with time is similar to that of temperature increase, and the distribution of cooling maxima is similar to that of warming maxima. During this particular period, there appeared to be favored locations of temperature-change centers at heights of 9–10 kilometers and of 23–35 kilometers, with an absence of major change centers between 12 and 20 kilometers. As additional data become available, it will be of interest to determine whether this condition remains consistent through longer time periods.

Geomagnetic and Ionospheric Disturbances at Time of 1958 Warming

On October 22, 1958, unusually intense sunspot activity was observed by theodolite from the South Pole Station. The relative sunspot number increased from 163 on the 21st to 214 on the 22nd. From October 14–21, the geomagnetic field, as observed at the South Pole Station had remained quiet and ionospheric absorption was normal, but at 0600 UT on the 22nd both became anomalous. A moderate geomagnetic disturbance lasting 9–10 hours was observed and ionosphere records indicated a rise in radio-wave absorption, followed one hour later by a sharp drop in F-2 critical frequency (the frequency above which radio waves completely penetrate the F-2 layer). At 1700 UT on the 22nd, very low critical frequencies, about 4½ megacycles per second, were observed in the F-2 region; critical frequencies did not rise above five megacycles on the 23rd, and did not reach the normal eight-megacycle level until 1700 UT on the 25th.

The onset of warming at the 10-millibar level was nearly concurrent with the beginning of the geomagnetic and ionospheric disturbances. On the other hand, the lowest daily total of sporadic-E clouds—clouds or patches of unusually high ionization in the

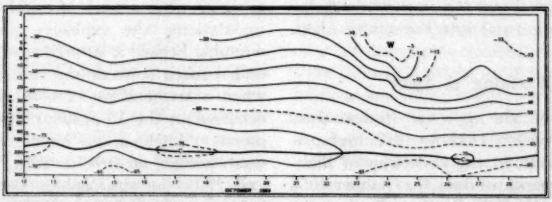

Fig. 12. *Time Section Showing Stratospheric Temperatures Over the IGY South Pole Station, October 12–29, 1958. Heavy line represents the mean tropopause.*

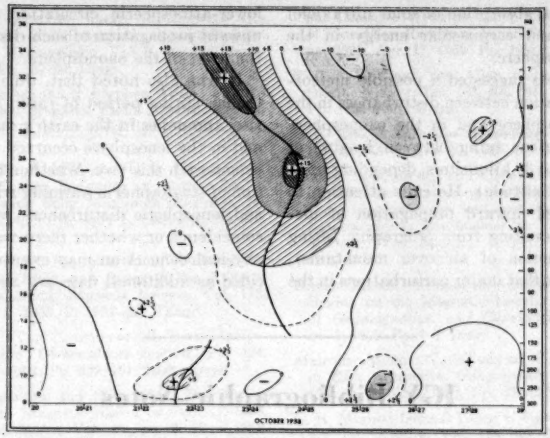

Fig. 13. *Time Section Showing Stratospheric 24-Hour Temperature Change Over the IGY South Pole Station, October 20–29, 1958.*

E-region (90–150 kilometers)—occurred on the 24th, the day that warming ended at the 10-millibar level.

Warming Elsewhere Over Antarctica

It is interesting to note that warming of nearly equal magnitude to that over the South Pole region swept over a large portion of Antarctica within a 24-hour period beginning on October 22. There is a suggestion that the atmospheric region of maximum temperature change, which was first observed at Ellsworth Station, next moved over the South Pole and, although diminished in intensity, was last centered over the polar plateau.

Plots showing the time of occurrence of maximum temperature at 50 millibars over a number of Antarctic stations also suggest this pattern of temperature change. The US-IGY Amundsen-Scott South Pole Station, as well as the USSR-IGY Sovietskaya and Vostok Stations, all located high on the polar plateau, were the last to observe the maximum temperatures. Despite the long distances between stations and the sparseness of data for the intervening regions, the suggestion is strong that both maximum temperature and maximum temperature change last occurred over the high plateau of East Antarctica.

Summary and Conclusions

Through the use of high-altitude sounding equipment and balloons, much was learned during the IGY about the south-polar stratospheric temperature structure in general, and about the extremely rapid spring warming in particular. It was observed that spring warming involves rapid daily temperature changes encompassing the stratosphere over most of Antarctica.

It is certain that circulation should be considered in attempts to explain the intimate relationship of temperature change to pressure change in these explosive warmings, and that these are associated in some

manner with absorption of solar ultraviolet radiation and corpuscular energy in the upper atmosphere.

Wexler has suggested a possible meteorological relation between disturbances in the lower atmosphere and in the ozonosphere (layer of ozone lying between heights of about 19 and 35 kilometers, depending upon season and latitude). He calls attention to the observed upward propagation of disturbances resulting from orographic lifting (upward motion of air over mountains), and suggests that major perturbations in the lower-atmospheric circulation could cause upward propagation of such disturbances to the level of the ozonosphere.

It was also noted that, during one particular spring period of rapid temperature rise, anomalies in the earth's magnetic field and in the ionosphere occurred nearly coincident with this rise. Whether the conjunction of stratospheric warming with magnetic and ionospheric disturbances was merely a coincidence or whether there was an actual physical connection may eventually be decided as additional data are accumulated.

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Glacial History of the McMurdo Sound Region, Antarctica

The following material is essentially a condensation of a report by Troy L. Péwé, US Geological Survey and Department of Geology, University of Alaska, College, Alaska. The more detailed version was issued by The Ohio State University Research Foundation as USNC-IGY Antarctic Glaciological Data Report Number 2, Part IX, Multiple Glaciation in the McMurdo Sound Region, Antarctica, *February 1960.*

An earlier report on preliminary results of investigations of the glacial geology of the McMurdo Sound region, Antarctica, appeared in *Bulletin No. 14.* The present report gives the results of further analysis of the field data; it includes a revised glacial chronology for the McMurdo Sound region and a speculative correlation of this chronology with the Pleistocene glacial chronologies of New Zealand and of North America.

Both this and the earlier *Bulletin* report are based on field observations to the east, south, and west of McMurdo Sound by Troy L. Péwé and Norman R. Rivard, made between December 1, 1957, and February 10, 1958.

Physiographic and Geologic Setting

The region just west of McMurdo Sound may be the largest relatively ice-free area in Antarctica. It is 10–50 miles wide, at least 100 miles long, and consists of alternating eastward-trending ridges and valleys. The continental ice cap has withdrawn entirely from the region. However, a few large *outlet glaciers* flow from the border of the ice cap through mountain passes toward the sea, and numerous small *alpine glaciers*, independent of the ice cap, originate in mountain valleys.

Relief in this region is generally between 3000 and 6000 feet; the greatest relief, about 13,000 feet, represents the rise from sea level to the highest peaks of the Royal Society Range, which dominates this part of South Victoria Land. (See Figure 1.)

Within the first 20–30 miles from the sea, the area is characterized by metamorphic rocks intruded by granite. The highlands farther west, including the Royal Society Range, consist of flat-lying sedimentary rocks and dolerite sills—bodies of basaltic rock intruded, in the molten state, parallel to the sedimentary bedding planes. The lowlands are covered with glacial deposits and many of the valleys contain alkaline lakes—remnants of lakes formed along the ice margins during the Pleistocene, or Glacial, epoch.

South and east of McMurdo Sound, ice-free land is much less extensive than to the west, consisting of a few volcanic regions, such as the cones of Mount Erebus and Mount Discovery, ranging in area from one to 50 square miles. Some of this volcanic

Fig. 1. *Inferred Extent of McMurdo Glaciation in McMurdo Sound Region, Antarctica. Extent of existing ice cover also shown. Key to abbreviations: D, Davis Glacier; DI, Dailey Islands; G, Garwood Glacier; H, Hobbs Glacier; M, Miers Glacier; NAF, Williams Naval Air Facility; S, Stranded Moraines. Base modified after US Navy Hydrographic Office Chart No. 6636 (Ross Sea) 3rd ed., September 23, 1957.*

terrain forms "islands" projecting through the Koettlitz Glacier and the Ross Ice Shelf.

The glaciers of the McMurdo Sound region are polar glaciers, having temperatures below freezing throughout the year. No water issues from beneath or within them, although some melt water flows from the glacier surfaces near their termini during December and January, in the middle of the austral summer. This water forms shallow streams for a few days a year. Some of the streams reach the sea but most drain into lakes in essentially ice-free valleys blocked by small glacier tongues or by moraines. The glacier regimes are sluggish and there appears to have been no perceptible advance or retreat of the glacier fronts during the past 50 years.

Glacial Chronology

The quaternary period of geologic time is represented in the McMurdo Sound region by deposits of at least four major glaciations, each less extensive than the preceding one. (The Quaternary period, approximately the last million years, is subdivided into the Pleistocene and Recent epochs; the latter dates from about 10,000 years ago to the present and is still in progress.)

The oldest of the four periods of glacial advance and retreat in the McMurdo Sound region is recognized by scanty deposits preserved only on high ridges, while the two next younger ice advances (grouped under one glaciation in the earlier report but now considered to represent two distinct glaciations) are marked by subdued moraines. The most recent glaciation left drift, or glacier-transported deposits of rock material, that still has cores of glacier ice.

The following material contains proposed names for geographic and glacial features, and for the four glaciations in the McMurdo Sound region. Some of the geographic names have been approved by the Board on Geographic Names, others have not been approved, and some are still under consideration. For convenience, this account uses the names used in the original report.

McMurdo Glaciation: Deposits of this oldest and most extensive glaciation occur at elevations up to about 5000 feet above sea level in valleys and on mountain slopes in the McMurdo Sound region (see Fig. 1). The Sound itself must have been filled with ice to an elevation of about 2000 feet. In general, these deposits occur high on ridges and flat areas and have little or none of the distinct topographic form characteristic of the various types of glacial moraines.

Patches of drift of the McMurdo Glaciation were found 2000 feet above sea level on ridges on the west side of Koettlitz glacier and about 3000 feet above sea level, and 2500 feet above the valley floor, near Mount Nussbaum in Taylor Dry Valley. Thus, the ice at these locations rose to at least these elevations during the glaciation. Koettlitz Glacier also coalesced with the Ross Ice Shelf, and Brown and Black Islands, 2300 and 3500 feet high, respectively, may have been completely covered. If Mount Dis-

covery was near its present height (about 9100 feet) during the McMurdo Glaciation, ice surrounded it to an elevation of approximately 5000 feet. On the flanks of Mount Erebus, on Ross Island, the ice may have reached an elevation of 2000 feet.

No information is available as to the farthest northward extent of ice in the Ross Sea during the McMurdo Glaciation, but Beaufort Island (see Fig. 1), if it existed, must have been completely overridden by the ice. Glacial sediments found previously on the sea bottom 300 to 400 miles north of the present front of the Ross Ice Shelf were probably rafted seaward by icebergs.

The antiquity of the McMurdo Glaciation is indicated by the lack of morainal form of the deposits, the high degree of weathering, and the fact that most of the boulders and cobbles in all exposures have been abraded to the level of the ground surface by the strong, persistent, sand- and silt-laden winds —a process that must have taken a very long time. The drift of younger glaciations, by comparison, is less severely wind eroded.

The old drift of the McMurdo Glaciation found in the vicinity of Mount Nussbaum is composed of granitic and metamorphic rocks; on the high ridges west of Koettlitz Glacier, some kenyte, a sodium-rich lava, is also found in this ancient drift. At an elevation of 2300 feet on Mount Nussbaum, large glacier-transported boulders (erratics) rest on marble bedrock, and on the west side of Davis Valley, below Davis Glacier, black, wind-polished cobbles of dolerite lie on marble bedrock at an elevation of about 2000 feet.

Taylor Glaciation: The next oldest recognizable glacial advance in the McMurdo Sound region is named the Taylor Glaciation, because of the widespread characteristic deposits on the floor and lower slopes of Taylor Dry Valley. Although this glaciation (see Fig. 2) was actually less extensive than the McMurdo Glaciation, the deposits left by it are more extensively preserved and have been recognized throughout the McMurdo Sound region.

Fig. 2. *Inferred Extent of Taylor Glaciation, McMurdo Sound Region. (See Figure 1 for key to abbreviations.)*

Deposits left by the small alpine glaciers during this glaciation (as well as succeeding ones) can be distinguished from those of the large outlet glaciers primarily by differences in rock types. The drift of the alpine glaciers is composed mainly of granite, marble, and gneiss, with some dolerite cobbles; that of Koettlitz Glacier, the main contributor of outlet-glacier drift, is rich in dark volcanic rocks, particularly kenyte. In valleys to the west of Koettlitz Glacier, boulders on the surface of the drift of Taylor age are wind-abraded, and smaller stones shaped by wind abrasion (ventifacts) are well developed, as are pebbly "desert pavement" surfaces such as those seen in windy desert regions.

A subdued morainal blanket mantling Taylor Dry Valley indicates that the Taylor Glacier filled the valley to an elevation of approximately 1000 feet during the Taylor Glaciation. The ice did not cover Mount Nussbaum, however, as it did in the McMurdo Glaciation.

The Ferrar outlet glacier advanced into McMurdo Sound as the ice cap expanded. Strong pressure from the greatly enlarged Koettlitz Glacier, to the south, evidently bent Ferrar Glacier northward around the

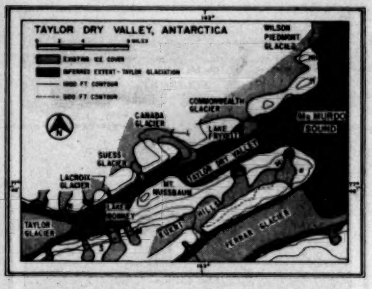

Fig. 3. *Inferred Extent of Taylor Glaciation in Taylor Dry Valley, Antarctica. Extent of existing ice cover also shown. Key to abbreviations: H, Hjorth Hill; HH, Hogback Hill; M, Marr Glacier; R, Rhone Glacier; S, Sollas Glacier. Base modified after map of Ferrar-Koettlitz District, British Antarctic ("Terra Nova") Expedition, 1910–13.*

base of the Kukri Hills, causing it to merge with the Taylor Glacier and bank up 1000 to 1200 feet above sea level around Hjorth and Hogback Hills (see Fig. 3). This ice then coalesced with the Wilson Piedmont Glacier north of Hogback Hill.

Koettlitz Glacier bulged laterally 4 to 5 miles up the now nearly ice-free, eastward-trending valleys along its west side (Fig. 2). On the east, it covered Brown and Black Islands and the slopes of Mount Discovery to a height of at least 2350 feet, and combined with the Ross Ice Shelf. The ice surface sloped downward to the north, and was probably 1000 feet or more above sea level on the west side of Ross Island.

Many glacial lakes formed when valleys on the west side of McMurdo Sound were blocked by ice or by moraines from the huge outlet glaciers during and just after the Taylor Glaciation. One such lake, a large one, 1000 feet in maximum depth, formed in Taylor Dry Valley when the glacial ice began to recede. The water was dammed in either by the ice front as it receded down the valley or by ice-cored moraines blocking the mouth of the valley. This long-extinct lake, referred to here as Glacial Lake Washburn, is represented by weakly developed but easily recognized shorelines, 1000 feet above sea level along the walls of Taylor Dry Valley and reaching up-valley to the present terminus of Taylor Glacier (see 1000-foot contour, Fig. 3). Other evidences of the existence of this ancient lake are many deltas and a widespread, thick deposit of laminated silt and clay in the valley bottom. The deltas and lake-bottom deposits were subsequently dissected by streams and overridden by later glacier advances.

Fryxell Glaciation: The next recognizable glacial advance, the Fryxell Glaciation, was less extensive than the Taylor Glaciation. The deposits of these two closely related glaciations are not everywhere easily differentiated. They can be readily distinguished, however, in Taylor Dry Valley, especially toward its lower end, where well-preserved moraines of the Fryxell Glaciation occur adjacent to an existing lake, here named Lake Fryxell, between Canada and Commonwealth Glaciers (see Fig. 4). Most alpine glaciers in this region carry little rock debris and leave only a thin drift, 1 to 2 feet thick, when they retreat. In the Taylor Dry Valley area, well-preserved moraines of the Fryxell Glaciation were found 100 yards to two miles in front of existing alpine glaciers.

The great age of this glaciation is indicated by well-developed desert pavement on the drift surface and by widespread, well-developed ventifacts. Also, small streams flowing for only a few days a year have had time to cut gullies and canyons through the drift. A series of raised marine beaches in front of Wilson Piedmont Glacier, the highest about 80 feet above sea level, also provide a crude measure of the age of the Fryxell Glaciation. The beaches formed and were uplifted after Wilson Piedmont Glacier withdrew from the coast, a process that must have taken a considerable length of time since McMurdo Sound is frozen most of the year.

The moraines of the alpine glaciers of the Fryxell Glaciation consist mainly of dolerite and of granitic and metamorphic

rocks. Those of Commonwealth Glacier, which formed during this glaciation, are rich in kenyte and blocks of sandstone. Moraines in the Koettlitz Glacier area, where recognizable, are also rich in kenyte, as well as in basalt.

During the Fryxell Glaciation, alpine glaciers in smaller valleys along the walls of Taylor Dry Valley expanded into the bottom of the larger valley (Fig. 4); in the upper end of Taylor Dry Valley, they coalesced to cover the sediments of Glacial Lake Washburn, which had existed in the interval between the Taylor and Fryxell Glaciation. Commonwealth Glacier, after spreading into Taylor Dry Valley, pushed a mile into McMurdo Sound, and Wilson Piedmont Glacier probably also extended a short distance into the Sound.

Koettlitz Glacier was less extensive during the Fryxell Glaciation than during the preceding one, advancing only 2 to 3 miles up the ice-free valleys to the west. Koettlitz Glacier probably did not stretch as far north as it did during the Taylor Glaciation, since the expanded ice tongue of Ferrar Glacier does not appear to have been again

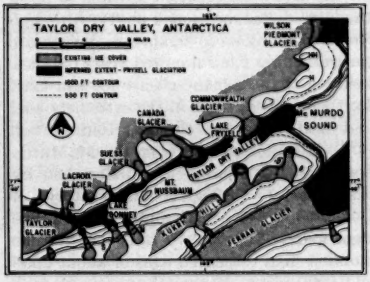

Fig. 4. *Inferred Extent of Fryxell Glaciation, Taylor Dry Valley.* (*See Figure 3 for key to abbreviations.*)

pushed northward against Hjorth Hill. Although the glacial ice in McMurdo Sound may have risen to a height of several hundred feet against the west side of Ross Island during the Fryxell Glaciation, it apparently did not extend far into the Ross Sea. However, it is possible that the kenyte found adjacent to Commonwealth Glacier was actually deposited by a lobe of the Koettlitz Glacier. If this is true, the ice may indeed have reached Hjorth Hill and pushed farther out into the Ross Sea.

A now extinct glacial lake, here referred to as Glacial Lake Rivard, existed between Canada and Commonwealth Glaciers in the lower part of Taylor Dry Valley toward the end of the Fryxell Glaciation. Weakly developed shorelines of this ancient lake are found at a number of step-like intervals between elevations of 150 and 55 feet above sea level; the latter is the present level of Lake Fryxell, a "living" remnant of the extinct lake. The intermediate shorelines represent stages in the shrinking of Glacial Lake Rivard. As the ice of the Fryxell Glaciation melted, a similar lake, Glacial Lake LLano, was also formed between Taylor and Canada Glaciers in the upper part of Taylor Dry Valley. The present Lake Bonney is a remnant of this ancient glacial lake.

Koettlitz Glaciation: The most recent and least extensive ice advance in the McMurdo Sound Region, the Koettlitz Glaciation, is represented by distinct and well-preserved deposits, of which the moraines on both sides of Koettlitz Glacier are particularly good examples. The moraines are still filled with stagnant glacial ice, making it easy to differentiate them from the older deposits of earlier glaciations.

Only the large outlet glaciers left widespread deposits during this glaciation. The drift of the alpine glaciers consists mainly of short, ice-cored lateral moraines, about 100 feet high, along the sides of the small, alpine-glacier valleys where they open out into the larger valleys of the outlet glaciers.

The ice-cored moraines exhibit well-developed, constantly shifting "knob and kettle topography," formed by the gradual wasting away of masses of glacier ice buried in the drift. No ventifacts have formed on the shifting surfaces of the ice-cored mo-

raines. These moraines are covered by a network of polygonally patterned ground—contraction cracks in frozen ground and stagnant ice, produced by the great seasonal temperature changes. The drift of the Koettlitz Glacier is composed largely of dark volcanic rocks; kenyte is common.

During the Koettlitz Glaciation, the alpine glaciers were only a few hundred yards farther advanced than they are at present. The outlet glaciers and the shelf ice, however, were relatively much more extensive. Koettlitz Glacier pushed 1 to 2 miles up into the small valleys to the west, and thickened considerably, rising to an elevation of 1700 feet above sea level on the flanks of Mount Discovery. The ice nearly covered Brown Island, where it reached an altitude of 1200 feet, and it covered the western part of Black Island to an elevation of at least 1000 feet. (See Figure 5.)

Fresh marble and gneiss erratics on the volcanic surfaces of the small Dailey Islands, which today project through the terminal portion of the Koettlitz Glacier to a height of about 800 feet above sea level, indicate that these "islands" were completely covered during this last glaciation. By projecting ice-surface profiles across the Sound, it is conjectured that the ice may have reached an elevation of 500 feet or more on the west side of Ross Island during the Koettlitz Glaciation. Granitic erratics on Cape Royds may have been deposited at this time.

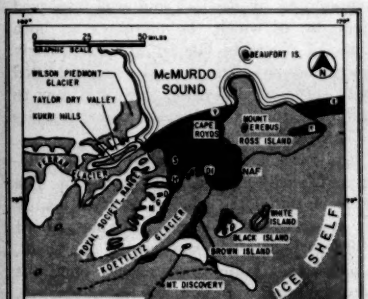

Fig. 5. *Inferred Extent of Koettlitz Glaciation, McMurdo Sound Region.* (*See Fig. 1 for key to abbreviations.*)

Ferrar Glacier advanced into McMurdo Sound as an ice tongue but probably was not pushed northward against Hjorth Hill, as it was in the Taylor and, possibly, the Fryxell Glaciations. Hence, glacier ice in the Sound probably did not advance into the Ross Sea, and Beaufort Island may not have been covered by ice from the south during this glaciation.

During the Koettlitz Glaciation, lobes of the Koettlitz Glacier pushed into the small valleys to the west, blocking drainage and forming ice-dammed lakes. Three distinct delta surfaces at descending levels are distinguishable in Davis and Garwood Valleys, indicating long intervals when the lake levels remained constant, perhaps in correlation with periods of stability of the glacier front.

The age of the Koettlitz Glaciation is not known, but considerable time was needed for the small, intermittent streams to build the large deltas mentioned above. Although ice-cored moraines in temperate regions are generally only a few hundred years old, it is believed that stagnant glacier ice can exist for thousands of years in the extremely cold and arid Antarctic climate. Radiocarbon (C^{14}) dating of samples from the McMurdo Sound glacial deposits was undertaken by the Lamont Geological Observatory of Columbia University. Samples of dried lake algae found at depths of 1 to 10 feet in some moraines had estimated ages of about 2500 and 6000 years. Hence, the minimum age of the Koettlitz Glaciation must be about 6000 years.

Correlations with Glacial Chronologies for Other Regions

In the absence of sufficient radiocarbon dating and of fossils similar to those found elsewhere in Pleistocene deposits, it is very

Table 1. Correlation of Pleistocene Chronologies*

McMurdo Sound	New Zealand	North America
Koettlitz Glaciation** Fryxell Glaciation	Otiran Glacial†	Wisconsin Glacial‡
		Sangamon Interglacial
Taylor Glaciation	Waimaungan Glacial	Illinoian Glacial
Long time interval	*Interglacial*	*Yarmouth Interglacial*
McMurdo Glaciation	Ross Glacial	Kansan Glacial
		Aftonian Interglacial
		Nebraskan Glacial

* It is extremely difficult to establish actual times for Pleistocene events since radiocarbon dating can be used for only the last 30,000–35,000 years; other radioactive decay techniques require ages greater than several million years; and techniques based on deposition and erosion times are too variable. Present estimates of the total length of the Pleistocene glacial epoch vary from about 300,000 to a million or more years.

** Possibly two or three substages, the last at least 6000 years ago.

† Four substages, the next-to-last about 22,000 years ago.

‡ Four substages have been recognized.

difficult to correlate the McMurdo Sound glacial chronology with those of other parts of the world. The attempted correlation with chronologies for New Zealand and North America (Table 1) is, therefore, speculative and preliminary. (The New Zealand chronology and the corresponding correlation with that for North America are based on a report by Maxwell Gage and R. P. Suggate, 1958.)

The glacial sequence suggested for the McMurdo Sound area may represent most of the Pleistocene epoch or only the Wisconsin stage of the North American chronology. The second interpretation is believed unlikely, however: even if rates of wind erosion and moraine modification in the McMurdo Sound region were twice as rapid as in the remainder of the world, the oldest glacial drift in the McMurdo region would still be at least pre-Sangamon in age.

The relation of the Antarctic ice-cap regimen to climatic variations is still unknown, but more light will be shed on the problem when IGY Antarctic data have been further analyzed. The glacial studies reported here show that the glaciers in the McMurdo Sound region have been retreating for at least 6000 years, and undoubtedly longer. Hence, although it is still too early to draw positive conclusions, it is suggested that climatic warming and glacier retreat have been taking place simultaneously in the Antarctic for the last few thousand years.

Pioneer V Preliminary Results

The following report is based on material provided by the National Aeronautics and Space Administration. It draws on papers presented at the Forty-First Annual Meeting of the American Geophysical Union, held in Washington, D. C., April 27–30, 1960, by the following participants: J. A. Simpson, C. Y. Fan, and P. Meyer, University of Chicago; C. P. Sonett, P. J. Coleman, Jr., E. J. Smith, and D. L. Judge, Space Technology Laboratories; J. A. Van Allen and B. J. O'Brien, State University of Iowa; and R. L. Arnoldy, R. A. Hoffman, and J. R. Winckler, University of Minnesota.

Preliminary analyses of observations made by US space probe 1960 Alpha (Pioneer V) have resulted in new information about cosmic rays and other radiations and about magnetic fields in interplanetary space. The probe was launched on March 11, 1960, and entered a heliocentric orbit between the orbits of Earth and Venus (see *Bulletin No. 34*).

In late March and early April, when 1960 Alpha was about 5,000,000 kilometers from the Earth, solar activity increased greatly, with the occurrence of many flares, radio-noise bursts, and associated terrestrial effects such as geomagnetic disturbances, auroras, and variations in both galactic and solar cosmic-ray intensity. The probe's observations during this period have been compared with related observations by the similarly instrumented earth satellite 1959 Iota (Explorer VII), and by balloons and ground-based recorders. Thus, for the first time, it was possible to observe these solar-terrestrial phenomena from a position in space between the Sun and Earth as well as at the Earth itself, adding another dimension to our picture of the processes involved.

This report is primarily concerned with observations made during the March-April period of increased solar activity.

High-Energy Radiation Measurements

1960 Alpha instrumentation developed by the University of Chicago has been measuring the intensity of high-energy radiation in space. Simultaneously, four neutron monitors have been recording changes in cosmic-ray intensity at the Earth. The following findings are reported by the University of Chicago experimenters on the basis of measurements made in late March and early April, and of comparisons and correlations between these and other data:

(1) On March 31, 1960, after 1960 Alpha had traveled a distance of 5,000,000 kilometers from the Earth, its instruments recorded a Forbush-type sudden decrease of galactic-cosmic-ray intensity of about the same magnitude as that of a Forbush decrease occurring simultaneously at the Earth. A similar correspondence with a decrease at Earth had previously been found by Explorer VI at distances greater than eight earth radii. Hence, the Forbush decrease must be associated with a heliocentric mechanism, and existing theories which relate this phenomenon to the Earth's magnetic field are proved invalid.

The sequence of events on this occasion is described as follows: An outstanding solar flare on March 30 sent a burst of plasma toward the Earth. The plasma reached 1960 Alpha and the Earth on March 31, and produced a typical geomagnetic storm, shaking and distorting the Earth's magnetic field (see Fig. 6). It also caused a sharp decrease in the intensity of high-energy cosmic-ray particles from the galaxy, both at 1960 Alpha's position in space and at the Earth.

(2) Pioneer V also made direct observations of particles accelerated in solar flares. Solar protons were detected by 1960 Alpha promptly following their acceleration on the Sun. At the same time, solar-flare

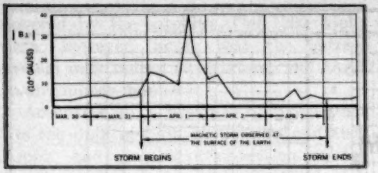

Fig. 6. *Magnetic Storm in the Interplanetary Field. Data from the 1960 Alpha magnetometer experiment, when checked against data obtained by magnetic observatories on the ground, show a direct correlation between the magnetic-field disturbance in interplanetary space and at the Earth. $B_\perp$ refers to the field component perpendicular to the probe's spin axis. STL graph.*

particles produced ionization in the Earth's atmosphere over the "polar cap," as shown by increased absorption of cosmic radio noise recorded at high latitude by H. Leinbach of the University of Alaska. This indicates that the solar flare particles that produce the polar-cap ionization for many hours at a time are not stored in the geomagnetic field, but move directly to Earth.

(3) Evidence was found of solar production of energetic electrons by processes other than solar flares. The presence of such electrons was inferred by the measurement, on many days, of Bremsstrahlung X-rays, which are formed by the sudden loss of velocity of electrons striking the probe's shell and the lead shielding on the detector.

Total Radiation Flux

University of Minnesota investigators reached two major conclusions from the recordings made thus far by the ionization chamber and Geiger counter they placed aboard 1960 Alpha:

(1) Solar cosmic rays were observed at a position in space completely free of the Earth's environment. One such observation was made previously, by 1959 Delta, which detected cosmic rays from a small flare on September 3, 1959, at a distance of 7 Earth radii. Outbursts of low-energy cosmic rays followed five or six flares during the March—April period of heightened solar activity. The intensities of the bursts ranged from just detectible above galactic cosmic-ray background to particle fluxes 10 times the galactic background intensity.

Such outbursts had previously been detected by balloon experiments during and following the IGY (see *Bulletin No. 35*). Similar balloon observations made by the University of Minnesota over the north-central United States during the March-April period of increased flare activity show a very good correlation, in one case at least, with the 1960 Alpha measurements. In addition, 1959 Iota observed two of these radiation bursts as the satellite passed over the Hudson Bay region.

Thus, even outside the Van Allen belts of high-intensity radiation trapped in the Earth's magnetic field, intense bursts of very penetrating radiation produced by solar activity may be encountered by space vehicles. Such radiation must be seriously considered for its biological effects.

(2) On March 31 and again on April 4, relatively weak electron fluxes were encountered by 1960 Alpha in the vicinity of 5,000,000 kilometers from the Earth. During the period April 2–7, intensity increases of 10–40 times normal were observed by 1959 Iota about 1000 kilometers from the Earth, in the outer radiation belt. These increases followed an initial "dumping" of particles from the outer belt (see below) on April 1, resulting in increased auroral activity. The intensity increases in the outer radiation belt were about 10,000 times those observed by 1960 Alpha in space.

The University of Minnesota experimenters suggest that the Earth's outer radiation belt may not be produced by direct injection of solar particles. They believe that the outer belt is built up by

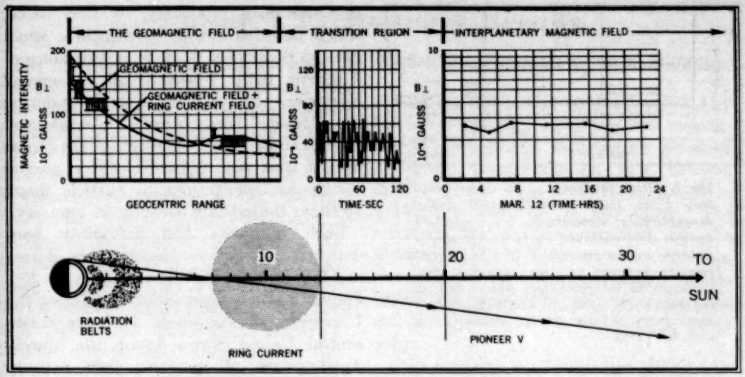

Fig. 7. *Extraterrestrial and Interplanetary Magnetic Field. The upper portion of the diagram shows field-strength measurements by 1960 Alpha during the first part of its flight—to a distance of about 34 earth radii; the flight path is shown schematically in the lower portion of the diagram. The model now emerging includes a ring current flowing around the Earth at a distance of 7 to 15 earth radii; intense disturbances at 12 to 14 radii, signifying the termination of the Earth's magnetic field; and a steady, quiet-day interplanetary field. STL graph.*

acceleration in the geomagnetic field of a portion of the solar plasma ejected by a flare. The weak electron fluxes observed in space by 1960 Alpha may represent the high-energy end of the radiation spectrum of the plasma.

Correlation with Explorer VII Measurements

State University of Iowa scientists responsible for the corpuscular radiation experiment carried by satellite 1959 Iota (Explorer VII) arrive at a picture of the formation of the outer belt that is virtually identical with that of the University of Minnesota group.

They add the suggestion that entry of the solar-plasma cloud disrupts the magnetic field of the Earth so that the radiation trapped there is "dumped" into the atmosphere, causing widespread auroras reaching to low latitudes. Such auroras were in fact reported following the magnetic storm of March 31, 1960, and at the same time, the intensity of the outer zone at 1000–1100 kilometers altitude dropped from 200 counts per second to less than 10 counts/sec. During the next week, however, the counting rate again rose, reaching a peak of 10,000 counts/sec on April 7 or 8, and then gradually declined to pre-storm levels.

1959 Iota observations of solar protons agreed in time of occurrence and intensity with those obtained by 1960 Alpha, a preliminary comparison shows.

Magnetometer Experiment

An anomaly in the magnetic field was noted at a distance from the Earth that agrees with the assumption of a hydromagnetic ring current. The 1960 Alpha measurements, confirming and supplementing those obtained by 1959 Delta (Explorer VI) on the night side of the Earth, show a marked departure from the dipolar geomagnetic field beyond 5 to 7 Earth radii. (See Figure 7.) At the time of the 1959 Delta observations, the closure of the current system could not be determined because of the limited region of space

covered by the satellite. The 1960 Alpha data, however, imply that the current system may indeed close around the Earth in an annular manner.

According to a preliminary model that fits the data of both 1959 Delta and 1960 Alpha, the circular cross-section of the doughnut-shaped current is centered at a distance of 10 Earth radii and is some 6 Earth radii in diameter (Fig. 7). Total current flow is of the order of 5,000,000 amperes.

If the above model is assumed, the current probably consists of low-energy particles, which would explain why it has gone unobserved by the high-energy detectors customarily used to investigate radiation particles. The region in which the magnetic field perturbation was noted is beyond the outer Van Allen radiation belt. The perturbation is such that a minimum in geomagnetic intensity occurs at a distance varying from day to day but generally between 5 and 7 Earth radii.

Confirming Pioneer I observations, 1960 Alpha also observed intense disturbances in the geomagnetic field at distances of 10 to 15 Earth radii; these disturbances appear to have a wave structure. Both 1960 Alpha and Pioneer I noted termination of the field at 14 Earth radii, which conflicts with the boundary distance established previously from observations of comets. Bringing these two classes of data into coincidence will require detailed investigations of momentum and energy transfer across the geomagnetic boundary.

Beyond the disturbed region, the field intensity fell rapidly to a value of 2.5 gammas. This value was sufficiently consistent, both before and after interplanetary magnetic activity and geomagnetic activity, to suggest that a permanent 2.5-gamma field perpendicular to the Earth's orbit may exist in interplanetary space near the Earth during the present portion of the solar cycle. Future experiments are needed to determine the origin of this interplanetary magnetic field.

Correlations of the magnetic records obtained by 1960 Alpha in space with cosmic-ray and geomagnetic data, particularly during times of heightened solar activity such as occurred on March 31, are now under study. Large changes in the component of the interplanetary magnetic field lying in a plane perpendicular to a line between 1960 Alpha and the Sun were noted in association with the ejection of solar-flare material. Figure 6 shows the storm character as measured in space by the probe's magnetometer.

Monochromatic Arcs in the Night Sky

The following report is based on more detailed accounts by F. E. Roach and E. Marovich of the Central Radio Propagation Laboratory of the National Bureau of Standards, Boulder, Colorado, which appeared in NBS's Journal of Research, *November-December 1959 and March-April 1960.*

Photometric auroral studies in low geomagnetic latitudes during the IGY revealed the presence on several occasions of subvisual "monochromatic" arcs detached from, and apparently independent of, visible auroral activity occurring simultaneously. The term monochromatic is used to indicate that, in these arcs, radiation at a wavelength of 6300 Angstroms is dominant over

radiation at 5577 A. The first is a red line and the second a green line of atomic oxygen; both lines are common in auroral and airglow spectra.

Monochromatic 6300 A arcs have probably escaped detection in the past because of their low intensities. The arcs discussed here, observed by the Fritz Peak, Colorado, and Rapid City, South Dakota, IGY aurora and airglow stations on the nights of September 29–30, 1957, and October 22–23, 1958, respectively, had maximum intensities of 6 to 7 kilorayleighs. (A Rayleigh, R, is a measure of light intensity obtained by multiplying brightness, in megaquanta/cm^2/sec/steradian, by 4π; an intensity of 100 kR is equivalent to that of a bright aurora.) Monochromatic 6300 A arcs of intensities below about 6 kR are invisible to the eye; those between 6 and 30 kR are visible but colorless; and those greater than 30 kR are visible as red arcs.

The arcs were detected with photoelectric photometers installed as part of an IGY network established primarily to study the usually sub-visual night airglow. Each photometer consists essentially of a rapid-scanning quadruple telescope, each provided with a narrow-band interference filter and a system for self-calibration. A photometer can thus measure the intensity distribution of faint radiations from the dark upper atmosphere in three different colors of light, each characteristic of specific atomic and molecular processes, and in a fourth color used for control purposes.

The Fritz Peak observations were made by L. R. Megill and those at Rapid City were made by J. E. Cruz. The photoelectric photometer network, under the direction of F. E. Roach, was an IGY project of the National Bureau of Standards.

Fritz Peak Observations

During the night of September 29–30, 1957, a photometer at Fritz Peak (geomagnetic latitude 49° N), observing the sky from horizon to horizon along the geographic meridian at a wavelength of 6300 A, recorded a pronounced intensity maximum near the zenith. A visual aurora was also seen on this night to the north of both the Fritz Peak and the Rapid City stations.

These observations complemented those of D. Barbier, at the Haute Provence Observatory, France (geomagnetic latitude 46° N), who reported a similar 6300 A arc on the same night. In a study of low-latitude auroral activity based on Haute Provence records between March 10, 1956, and September 29, 1957, Barbier had found evidence of monochromatic 6300 A auroral activity on 31 nights. Almucantar sweeps with two of his photometers, usually set to circle the sky at a zenith distance (angle of arc from the zenith) of 75°, showed two distinct types of 6300 A auroral activity: i) a pronounced increase in brightness toward the north, and ii) increases in brightness at two different azimuths—one slightly north of west and the other slightly north of east.

Barbier noted that the second type may be accompanied by an increase in brightness at the celestial pole but not appreciably at the zenith. He interpreted the double maxima as indicating a 6300 A arc extending roughly east-west across the sky and crossing the meridian somewhere between the zenith and the northern horizon. Well-defined arcs of this type occurred on four of the 31 nights studied, including September 29–30, 1957. In a statistical study of 6300 A auroras at Haute Provence, Barbier found that they occur about 10% of the observing time and that they are in the form of distinct arcs 1.3% of the observing time.

The maximum intensity of the 6300 A arc observed at Fritz Peak was about 7 kR; hence, it was below the visual threshold for red light. The usual zenith intensity of the 6300 A radiation of the night airglow, however, is 100 to 200 R. Thus, the observed arc was some 50 times the normal

intensity of 6300 A nighttime radiation. The arc slowly decreased in intensity during the night, after reaching a maximum at about 2130 MST.

It was not possible to infer that the radiation was in the form of an arc solely from the zenith enhancement shown by the horizon-to-horizon meridional sweeps of the Fritz Peak instrument. However, the assumption of such structure is reasonable when these records are interpreted in the light of Barbier's correlative results. Comparison of instrument records from the two observatories shows that the end of the observing night at Haute Provence coincides almost exactly with the start at Fritz Peak, and suggests that a monochromatic 6300 A auroral arc persisted for at least 12 hours over a distance of at least 110° of longitude, or about one-third of the way around the world (see Fig. 8).

A systematic southerly movement of the

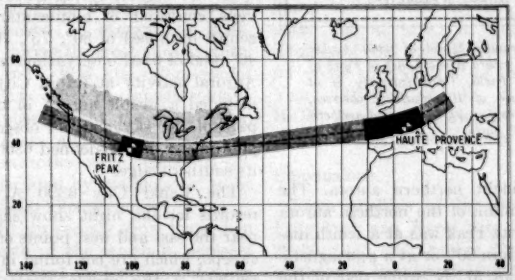

Fig. 8. *Possible extent of Monochromatic 6300 A Arc (intermediate pattern) on September 29–30, 1957. Darkest pattern represents portions of arc actually observed at Fritz Peak, Colorado, and Haute Provence, France; dashed line is approximate position of arc's photometric center. Lightest pattern represents visual aurora as seen from Fritz Peak.*

arc from midnight to about 0300 was noted by the Fritz Peak observers. During this interval the region of peak intensity (the photometric center) moved from a zenith distance of 1° S to 16° S. Interpreted in geographic terms, and assuming an emission height of 300 kilometers, the total movement of the photometric center of the arc was only about 80 kilometers, or less than 1° of geographic latitude. The speed of movement during this interval was equivalent to about 6.5 m/sec at the assumed height of 300 kilometers.

If the center of the arc seen from the Haute Provence Observatory is assumed to have been at a northerly zenith distance of 50°, it would have been about 3° of latitude north of the observatory, or at geomagnetic latitude 49° N. This is also the latitude of Fritz Peak, where the arc was seen directly overhead, further confirming the picture presented in Figure 8.

The Fritz Peak observations show the southern edge of the monochromatic auroral arc to be steeper than the northern, an effect to be expected if the arc has significant extent along the lines of force of the earth's magnetic field as well as in latitude. Figure 9 illustrates this situation for an arc with peak intensity 10° S of the zenith, at a height of 300 kilometers, and with its southern extreme at a zenith angle of 40° S and its northern extreme at a zenith angle of 60° S.

Although a well-defined visual aurora occurred near the northern horizon during the night at both Haute Provence and Fritz Peak, there is no evidence that the intensity of the 6300 A arc was influenced

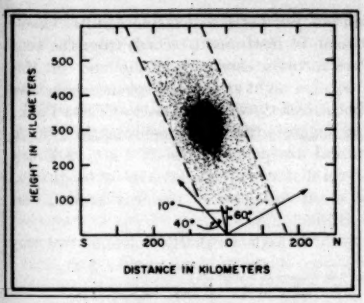

Fig. 9. *Schematic Model of 6300 A Arc Extending Upward Along Lines of Force of Geomagnetic Field. Peak intensity is at zenith distance of 10° south of observer, southern extreme is 40° south, and northern extreme is 60° north.*

by the coincident northern aurora. The intensity maximum of the northern aurora observed at Fritz Peak was at a zenith distance greater than 80°, or at a geomagnetic latitude of about 57° N, while that of the 6300 A arc remained near the zenith. The two phenomena were thus separated by at least 8° of latitude, or about 900 kilometers (see Fig. 8). It is possibly significant, however, that the southern edge of the visual aurora was very close to the northern edge of the sub-visual red arc.

The narrowness of the 6300 A monochromatic arcs suggests an analogy with localized features of visual auroras. Moreover, Barbier has shown a positive correlation between the 6300 A arcs observed at Haute Provence and geomagnetic activity. It is of interest, therefore, to consider the relationship of these arcs to the earth's magnetic field and, in particular, to the Van Allen belts of radiation trapped in the magnetic field. (see *Bulletin No. 30*). It is noted that the position of the magnetic line of force along which the 6300 A arc of September 29–30, 1957, occurred bears approximately the same relationship to the inner Van Allen belt as that of the auroral zone (geomagnetic latitude 67°) bears to the outer belt. Thus, the possibility is suggested that the inner belt may be responsible for the 6300 A monochromatic arcs and the outer belt for the more northerly visual auroras.

Rapid City Observations

During the night of October 22–23, 1958, the photometer at Rapid City, South Dakota (geomagnetic latitude 53° N), made systematic sky surveys in three bands of the spectrum—5577, 6300, and 5893 A. The surveys consisted of almucantar sweeps at zenith distances of 80°, 75°, 70°, 60°, and 40°, and of fixed observations of the zenith. Auroral activity at Rapid City that night included a visible aurora in the northern part of the sky and, as observed by the photometer, a well-defined 6300 A arc near its southern edge.

The Rapid City 6300 A photometer records for the night show sharp maxima near the east and west points of each of the sweeps, which are not found in the 5577 A records of the visible aurora. When an isophote map is drawn from these observations, the spike-shaped maxima define a 6300 A arc extending across the sky in a general east-west direction (see Figure 10).

The monochromatic arc remained independent, both geographically and in terms

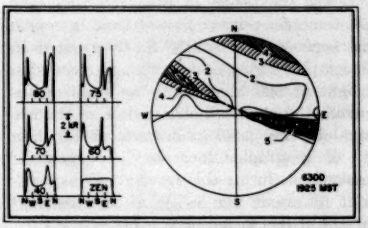

Fig. 10. *Original 6300 A Photometer Records for 1925 MST, October 22, 1958, at Rapid City, and Corresponding Isophote Map. A height of 300 kilometers was assumed in drawing the isophote map. Numbers on photometer records indicate zenith distances of almucantar sweeps; those on isophote map indicate intensity in kR.*

of intensity, of the bright visible aurora which developed in the northern part of the sky. The northern aurora went through strong variations of intensity, ranging from about 5 to 25 kR, while the intensity of the 6300 A arc remained within 1 to 6 kR and decreased steadily during the night.

The 6300 A arc moved steadily southward throughout the night at a mean speed of 8 meters per second for an assumed height of 300 kilometers. This compares with 6.5 m/sec for the arc observed September 29–30, 1957, at Fritz Peak, 58 m/sec for one that occurred at Sacramento Peak, New Mexico, during the great auroral storm of February 10–11, 1958, and 100 m/sec for 5577 A airglow cells. (A monochromatic 6300 A arc observed by the Fritz Peak, Sacramento Peak, and Cactus Peak, New Mexico, observatories on November 27–28, 1959, was calculated by triangulation to be at a height of 400 kilometers.)

The Rapid City records show that when the arc is north of the zenith it increases in brightness toward the horizon, but when it moves south of the zenith there is a decrease in brightness toward the horizon. This phenomenon is consistent with an assumption that the arc is inclined to the vertical, extending upward along the magnetic lines of force. When the arc is north of the zenith, as it would be for an observer at "S" in Figure 9, the observer tends to look across the arc when he faces north. This favors a lower apparent intensity toward the north and higher intensity eastward and westward along the arc, toward the horizon. As the arc moves south of the zenith, as for an observer at "N" in Figure 9, the observer looks upward along the arc, favoring a larger effective brightness near the zenith.

The various plots of the photometer data present a picture of a curved arc with an effective height of at least 300 kilometers and oriented west-northwest—east-southeast. The curvature of the arc can be explained by assuming that it follows a parallel of latitude (Fig. 8). Actually, however, the observed arc is inclined to the magnetic parallels by an angle of about 9°, since magnetic north at Rapid City is about 14° east of geographic north whereas a perpendicular to the arc would be almost 23° east. The arc is also inclined to the geomagnetic parallels, by about 12°.

The western part of the arc is north and the eastern part south of the magnetic and geomagnetic parallels. The inclination of these 6300 A monochromatic arcs is thus found to be similar to that observed for polar auroral arcs; L. Vegard and O. Krogness found an inclination of about 10° for arctic auroral data for the First Polar Year, 1882–83, and R. E. Jensen and B. W. Currie report a mean inclination of 6° for Canadian observations.

Conclusions

From analysis of the observations at Fritz Peak and Rapid City on September 29–30, 1957, and October 22–23, 1958, and of those of Barbier at Haute Provence, it is believed that there is a family of low latitude auroras with the following characteristics:

(1) The auroral activity is monochromatic in nature, with 6300 A radiation dominant over that at 5577 A; this implies that the excitation mechanism involved can excite the oxygen atom to its ^1D state (2.0 electron volts) but not to its ^1S state (4.2 ev).

(2) These sub-visual auroras occur at geomagnetic latitudes as low as, but probably not lower than, 48°.

(3) They may occur as arcs slightly inclined to the perpendicular to the earth's magnetic field.

(4) Although they may be concurrent with visible auroras, and possibly are a general feature on the equatorial side of all auroras, the monochromatic arcs are independent of the visible auroras with respect to geographic position and absolute intensity.

It is thought that there may be a relationship between the 6300 A arcs and the Van Allen radiation belts. The Rapid City arc corresponds to a dipole line of force cutting the magnetic equator at a distance of 2.8 earth radii from the center of the earth, just inside the inner edge of the outer radiation belt.

Monochromatic 6300 A arcs have also been observed in the Southern Hemisphere. R. A. Duncan reports observations of such an arc at Camden, Australia (geomagnetic latitude 42° S), on September 5, 1958. If a height of 300 kilometers is assumed, the arc's apex was 820 kilometers, or 7.5° of latitude, south of the station. This would place it at geomagnetic latitude 49.5° S.

IGY Bibliographic Notes

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